Faculdade de Desporto da Universidade do Porto

The influence of cleats model on predisposing factors for lateral ankle sprain and on the performance of soccer players in artificial grass

(Influência do tipo de chuteiras em fatores predisponentes para a entorse lateral do tornozelo e na performance de futebolistas, em relvados artificiais)

Thesis submitted in fulfilment of the requirements for the degree of Doctor in Physiotherapy by Faculdade de Desporto da Universidade do Porto, under the terms of Decree-Law nº 74/2006 24th March.

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This project involved the following entities: Faculdade de Desporto da Universidade do Porto (FADEUP); Laboratório de Biomecânica do Porto (LABIOMEP); Escola Superior de Saúde do Politécnico do Porto (ESS - P. Porto); Centro de Estudos do Movimento e Atividade Humana (CEMAH); Centro de Investigação em Actividade Física, Saúde e Lazer (CIAFEL); Relvados e Equipamentos Desportivos (RED) and ADIDAS Portugal.

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KEYWORDS: CLEAT-SURFACE INTERACTION; PREVENTION; KINETICS; KINEMATICS; NEUROMUSCULAR VARIABLES

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STATEMENT OF ORIGINALITY

I hereby certify that all the work described in this thesis is the original work of the author. Any published (or unpublished) ideas, techniques, or both from the work of others are fully acknowledged by the standard referencing practices.

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February 2018

ETHICAL DISCLAIMER

Ethical approval for the studies mentioned in this thesis has been granted by the Ethics Committee of Escola Superior de Saúde, Politécnico do Porto (processes number: 0779/2014; 1719/2014; 1331/2015 - Appendix I).

All subjects who participated in the studies were free from any physical impairment and signed an informed consent form. All participants were fully informed about the nature and objectives of the studies (Appendix II).

LIST OF PUBLICATIONS

Journals

1- Silva DCF, Santos R, Vilas-Boas JP, Macedo R, Montes A, Sousa ASP. Influence of Cleats-Surface Interaction on the Performance and Risk of Injury in Soccer: A Systematic Review. Applied Bionics and Biomechanics 2017:1-15.

2- Silva DCF, Santos R, Vilas-Boas JP, Macedo R, Montes A, Sousa ASP. The influence of different soccer cleat type on kinetic, kinematic and neuromuscular ankle variables in artificial turf. Footwear Science 2017;9(1):1-11

3- Silva DCF, Vilas-Boas JP, Mesquita CC, Maia J, Santos R, Peixoto T, Brito N, Andreia ASP. Portuguese version of the ankle instability instrument. Submitted for publication.

4- Silva DCF, Santos R, Vilas-Boas JP, Macedo R, Montes A, Sousa ASP. Different cleat models do not influence Side Hop Test performance of soccer players with and without chronic ankle instability. Submitted for publication.

5- Silva DCF, Santos R, Vilas-Boas JP, Macedo R, Montes A, Sousa ASP. Does the cleat model interfere with ankle sprain risk factors in artificial grass? Submitted for publication.

Conferences / Books

1- Silva, D. C. F; Macedo, R.; Sousa, A. S. P..; Montes, A.; Santos, R. Influência do tipo de chuteira na entorse lateral do tornozelo - 6th Portuguese Congress of Biomechanics: book of abstracts - Leiria 2015.

2- Silva, D. C. F.; Sousa, M.; Moreira, M.; Montes, A.; Santos, R.; Vilas-Boas, J. P.; Sousa, A. S. P. Influência do modelo de chuteira na performance de futebolistas com e sem instabilidade crónica do tornozelo. 7th Portuguese Congress of Biomechanics: book of abstracts - Guimarães 2017.

Scientific posters

1- Silva, D. C. F., Santos, R., Vilas-Boas, J.P., Macedo, R., Montes, A., Sousa, A. S. P. Influência do modelo de chuteira em variáveis cinéticas, neuromusculares e de performance em futebolistas sem e com instabilidade crónica do tornozelo - Reunião Internacional da Rede Académica das Ciências da Saúde da Comunidade dos Países de Língua Portuguesa – RACS - Lisboa 2017.

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ABSTRACT

Introduction: The cleats, had been subject to structural changes along the years to deal with the demands of soccer in different playing fields. Despite the recognition of their ability to influence both injury risk in some pathologic conditions and performance, their interaction with the playing field in the risk of one of the most prevalent injury in soccer – ankle sprain - has been poorly explored, deserving more attention. **Aims**: Study the influence of different cleat models on lateral ankle sprain injury risk and performance of soccer players with and without Chronic Ankle Instability (CAI). **Methods**: 81 participants with (n=59) and without (n=22) history of ankle sprain were recruited to perform the cultural adaptation of the Portuguese version of Ankle Instability Instrument to identify the presence of CAI (article III). A total of 145 non-professional soccer players (60 with and 85 without CAI) performed the Side Hop Test and the 6-meter Crossover Test with different cleat models to assess variables related to predisposing factors for lateral ankle sprain, as well as sports performance. **Results**: The evidence demonstrates that the Turf cleat model is protective for repeated impact injuries, while Soft Ground model in dry/wet artificial grass fields and the Turf model in wet fields lead to worse performance (article I). The results obtained in the present thesis demonstrated: 1) no differences in variables related to the risk of lateral ankle sprain between the Turf, Hard and Firm Ground models, even after a peroneal muscles fatigue protocol (article II n=24 healthy); 2) no differences in performance between Turf, Artificial Grass, Hard and Firm Ground models (n=19 healthy, n=20 CAI, article IV); 3) that Artificial Grass model lead to an earlier peroneus longus activation compared to the Turf model in the group with CAI. This group presented a later peroneus longus activation compared to healthy participants with Turf model (n=42 healthy, n=40 CAI, article V). **Conclusion**: Models authorized for artificial grass appear to have no influence in performance during changes of direction with associated jumps, in both healthy and players with CAI. Contrary to the Turf model, the Artificial Grass model seems to provide a higher protection for lateral ankle sprains in individuals with CAI compared to the other models evaluated.

KEY WORDS: CLEAT-SURFACE INTERACTION; PREVENTION; KINETICS; KINEMATICS; NEUROMUSCULAR VARIABLES

RESUMO

Introdução: As chuteiras têm sofrido, ao longo dos anos, alterações estruturais de modo a lidar com as exigências do futebol nos diferentes terrenos de jogo. Apesar do reconhecimento da sua capacidade para influenciar o risco de lesão de algumas condições patológicas e a performance, a sua interação com o terreno de jogo no risco de uma das lesões mais prevalentes no futebol – entorse do tornozelo – tem sido pouco explorada, merecendo mais atenção. **Objetivos**: Estudar a influência de diferentes modelos de chuteiras no risco de entorse lateral do tornozelo e performance de futebolistas com e sem Instabilidade Crónica do Tornozelo (ICT). **Métodos**: 81 participantes com (n=59) e sem (n=22) história de entorse do tornozelo foram recrutados para realizar a adaptação cultural da versão portuguesa do Ankle Instability Instrument para identificar a presença de ICT (artigo III). Um total de 145 futebolistas não profissionais (60 com e 85 sem ICT) realizaram o Side Hop Test e o 6-meter Crossover Test com diferentes modelos de chuteiras para avaliar variáveis relacionadas com fatores predisponentes para entorse lateral do tornozelo, bem como com a performance desportiva. **Resultados**: A evidência demonstra que o modelo de chuteira Turf é protetivo para lesões de impacto repetido, enquanto o Soft Ground em relvados artificiais secos/húmidos e o modelo Turf em terrenos húmidos induzem pior performance (artigo I). Os resultados obtidos na presente tese demonstram: 1) nenhuma diferença nas variáveis relacionadas com o risco de entorse lateral do tornozelo entre os modelos Turf, Hard e Firm Ground, mesmo após um protocolo de fadiga dos músculos peroniais (artigo II n=24 saudáveis); nenhuma diferença na performance entre os modelos Turf, Artificial Grass, Hard e Firm Ground (n=19 saudáveis; n=20 ICT, artigo IV); 3) que o modelo Artificial Grass conduziu a uma ativação mais precoce do longo peronial em relação ao modelo Turf no grupo com ICT. Este grupo apresentou uma ativação do longo peronial mais tardia com o modelo Turf em comparação com os participantes saudáveis (n=42 saudáveis, n=40 ICT, artigo V). **Conclusão**: Os modelos autorizados para uso em relvado artificial parecem não influenciar a performance durante mudanças de direção com saltos associados, tanto em saudáveis, quanto em atletas com ICT. Contrariamente ao modelo Turf, o modelo Artificial Grass parece ser protetor para entorses laterais do tornozelo em indivíduos com ICT.

PALAVRAS-CHAVE: INTERAÇÃO CHUTEIRA-TERRENO; PREVENÇÃO; CINÉTICA; CINEMÁTICA; VARIÁVEIS NEUROMUSCULARES

LIST OF ABREVIATURES

%	Percent
<	Smaller than
>	Greater than
°	Degrees
°/s	Degrees per second
Ω	Ohms
a-p	Anteroposterior
AEIROM	Ankle eversion/inversion range of motion
AG	Artificial grass
AII	Ankle Instability Instrument
bpm	Beats per minute
CAI	Chronic ankle instability
CAIT	Cumberland Ankle Instability Instrument
cm	Centimetres
COP	Center of pressure
COPx	Medio-lateral displacement of the center of pressure
COPy	Antero-posterior displacement of the center of pressure
EMG	Electromyography
FG	Firm ground
FIFA	Fédération Internationale de Football Association
Fx	X axis ground reaction forces
Fy	Y axis ground reaction forces
Fz	Z axis ground reaction forces
g	Grams
GRF	Ground reaction force
HG	Hard ground
Hz	Hertz
ICC	Intraclass Correlation Coefficient
IdFAI	Identification of Functional Ankle Instability
Kg	kilogram

KR-20	Kuder-Richardson test
LAS	Lateral ankle sprain
LRVx	Loading rate of the medio-lateral ground reaction force
LRVz	Loading rate of the vertical ground reaction force
m	Meters
MI	Mechanical instability
mm	Millimeters
ms	Milliseconds
m-l	Mediolateral
m/s	Meters per second
MVC	Maximum voluntary contraction
N	Newton
PB	Peroneus brevis
PI	Perceived instability
PL	Peroneus longus
PB_AT	Peroneus brevis activation time
PL_AT	Peroneus longus activation time
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analysis
rho	Tetrachoric correlation
RMS	Root mean square
ROM	Range of motion
rpm	Rotation per minute
RS	Recurrent sprains
s	Seconds
SD	Standard deviation
SG	Soft ground
TF	Turf
TV	Television
V_COPx	Medio-lateral speed for displacement of the Center of Pressure
V_COPy	Antero-posterior speed for displacement of the Center of Pressure

1. INTRODUCTION

Involving 4% of the world's population (270 million) (Kunz, 2007), soccer is undoubtedly the most popular sport in the world (Conenello, 2010; Kunz, 2007; Unlucan, 2014). The competitiveness of this sport requires that soccer players must be able to run, sprint, stop, jump, tackle and make rapid changes of direction while passing the ball or keeping it under control (Conenello, 2010; Lees & Nolan, 1998). These particularities highlight the cleats as an important piece of soccer equipment (McPoil, 2000; Sterzing, 2016) and the type of fields as a particularly important environment interface (Villwock, Meyer, Powell, Fouty, & Haut, 2009).

Soccer is traditionally an outdoor sport played on natural grass fields (Sterzing, 2016). However, the structural quality of natural grass fields depends on the climatic conditions, time of use and its response to wear (Lees & Nolan, 1998). Therefore, inappropriate surface conditions influence ball bounce and roll and, consequently, the style/strategy of the game. To avoid these problems the Fédération Internationale de Football Association (FIFA) encouraged the implementation of the artificial grass fields (FIFA, 2009, 2012; Sterzing, 2016). This recommendation aimed to overcome the limitations of natural grass fields favouring the practice of the modality regardless the climatic conditions while decreasing maintenance costs (FIFA, 2009, 2012). Over the years, the artificial grass features have been adapted to mimic the natural grass. Thus, three different generation of artificial grass have been developed. The first generation was created in 1960 and presents a concrete bottom layer covered with a relatively short artificial fiber carpet with no infill. The second generation, created in 1980, presents an elastic bottom layer and longer grass fibers with sand infill. The third generation, developed ten years later, presents the elastic bottom layer with sand and rubber infill and even longer fibers (Sterzing, 2016). The latest generation was designed to reduce the high frequency of injuries related to poor shock attenuation properties or skin burns during sliding tackles/falls, and to the inadequate cleat-surface interaction registered in the early generations (Sterzing, 2016). Despite the adequacy of soccer footwear to artificial grass fields has been postulated to have a determinant role in both performance and injury risk (Hennig, 2011; Kulessa, Gollhofer, & Gehring, 2017; McPoil, 2000; Sterzing, 2016), unfortunately, available epidemiologic research on sports injuries does not mention the cleat model used by players at the time of the injury (Sterzing, 2016). It should be also considered that in the early years when artificial grass fields began to be used, sports footwear manufacturers failed to keep pace with the changes, and athletes used models that were originally made for natural grass in artificial fields (Sterzing, 2016).

The main characteristics that distinguish the cleat models are related to the pattern, geometry, number and height of the studs (Lees & Nolan, 1998). Currently there are five types of soles: Turf (TF), Artificial grass (AG), Hard Ground (HG), Firm Ground (FG) and Soft Ground (SG) (Conenello, 2010; Queen et al., 2008). According to the manufactures, the TF and AG models are suitable for artificial fields and HG model for hard natural or dirt soccer fields. The FG model is indicated for natural grass in good conditions, while the SG to very muddy or wet natural fields (Queen et al., 2008). Specific artificial grass cleats based on general manufacturing guidelines ensuring large number of relatively short stud elements are now available in the market (Sterzing, 2016). It has been recommended that the grip must be sufficient to prevent slip and facilitate turning manoeuvres (Conenello, 2010), but it should be also considered that excessive fixation has been implicated in non-contact injuries during turning and cutting manoeuvres associated to increased torque on lower extremity joint structures (Lambson, Barnhill, & Higgins, 1996). This duality turns relevant the evaluation of the cleat-surface interaction in both performance and risk of injury.

The importance of the cleat-surface interaction in artificial grass conditions in ankle sprain predisposing variables should be highlighted because the ankle is considered one of the most injured body region in sports, accounting for 10-30% of all sports injuries (Fong, Hong, Chan, Yung, & Chan, 2007). Specifically, ankle sprain represents 76% of all ankle injuries in soccer (Fong et al., 2007; Kobayashi & Gamada, 2014; Ridder et al., 2015), involving affection of lateral ankle ligaments in 77-80% of the cases (Fong, Chan, Mok, Yung, & Chan, 2009; Garrick, 1977; Garrick & Requa, 1988). An impressive 650.000 sports-related ankle injuries can occur in a single country (Netherlands) and the lateral ankle sprain (LAS) incidence rates could reach 1,5-7 per 1.000 person-year in the general European population (Kemler et al., 2016). In fact, its prevalence is of concern in Europe, but also in the rest of the world, regardless of age, sex and competitive level (Doherty et al., 2014; Fong et al., 2007). The most common injury mechanism is characterized by forefoot adduction, hindfoot internal rotation, ankle inversion in plantar flexion, and external rotation of the leg beyond anatomical constraints during landing from a jump, stepping into a hole, and/or landing on a competitor's foot (Martin, Davenport, Paulseth, Wukich, & Godges, 2013). Regarding risk factors, the footwear type and playing field have been reported has the most important extrinsic risk factors for ankle sprain in soccer players (Beynnon, Murphy, & Alosa, 2002; Martin et al., 2013). Although fatigue is not usually referred to as a risk factor, should be seen as such, based on the high frequency of ankle sprains in soccer players on the second half of matches (Hawkins & Fuller, 1999; Tsiganos, Sotiropoulos, & Baltopoulos, 2007). The cleats' influence on sports injuries has been studied by several authors (Bentley, Ramanathan, Arnold, Wang, & Abboud, 2011; Brock et al., 2014; Butler, Russell, & Queen, 2014; Gehring, Rott, Stapelfeldt, & Gollhofer, 2007; Kaila, 2007; Müller, Sterzing, Lake, & Milani, 2010; Queen et al., 2008; Silva et al., 2017b; Smith, Dyson, & Janaway, 2004; Stefanyshyn, Lee, & Park, 2010; Walter & Ng, 2002). However, according to our knowledge no study stablished as primary objective the study of cleats' influence in the contributor variables for LAS. Based on biomechanical foundations it can be hypothesised that the cleat models that promote high traction levels can stress the ligament and muscle structures, which may possibly lead to LAS. Furthermore, studs that do not fully penetrate the ground may induce instability due to reduced contact area with the ground and, therefore, possibly lead to LAS. The impact of this mechanical restrains in LAS risk could be highlighted in fatigue condition induced by general or local exercises since this condition contributes to reduced effectiveness of the sensory input and the motor output of the postural system (Paillard, 2012). In fact, for an intermittent exercise such as soccer match, it has already been described that dynamic balance performance decreases during the last 15 min of each half period (Greig & Walker-Johnson, 2007). So, postural control deficits related to fatigue induced by exercise may be explained by metabolic activation and their products, as well as dehydration or sensorial alterations (visual, vestibular and proprioceptive) (Paillard, 2012). An increased mechanical demand and the respective impact on joint stability in a fatigued state has greater implications because impaired proprioception might alter the coordination of muscle activation, creating inadequate stabilisation of the joint and impaired control of joint motion favouring the risk of LAS (Greig & McNaughton, 2014). Despite all this, the influence of different cleats on the LAS injury risk under fatigue is still unknown.

When a LAS occurs, involves partial or complete disruption of the lateral ankle ligaments (anterior talofibular ligament, calcaneofibular ligament and posterior talofibular ligament) and can be classified as grade I, II or III (Fong et al., 2009; Martin et al., 2013). The impact of LAS is related to the lesion of these structures, the possibility of lesion of other structures such peroneal tendons, lateral subtalar ligaments, nerve injury extensor or peroneal retinaculum, inferior tibiofibular ligament, and osteochondral lesions of the talus (Martin et al., 2013), but also by the high prevalence of chronic ankle instability (CAI) (Doherty et al., 2014; Fong et al., 2007; Kobayashi & Gamada, 2014; Pourkazemi, Hiller, Raymond, Nightingale, & Refshauge, 2014). Chronic ankle instability has been defined in several ways but is more commonly described as “an encompassing term used to classify a subject with both mechanical and/or functional instability of the ankle joint” (Hertel, 2002; Martin et al., 2013). The mechanical instability has been described as excessive joint motion in the talocrural and subtalar joints (Hertel, Denegar, Monroe, & Stokes, 1999; Martin et al., 2013), and was described in 38% of soccer players with a previous ankle sprain (Attenborough et al., 2014). On the other hand, functional ankle instability englobes reports of instability due to sensorimotor and/or neuromuscular deficits (Hertel, 2008; Martin et al., 2013), and was described in 45% of soccer players that report persisting symptoms such pain, swelling, “giving away” and “instability” following an ankle injury (Attenborough et al., 2014). The impact of this clinical condition is substantial and includes deficits in neuromuscular control, strength, range of motion and proprioception (Martin et al., 2013). However, the influence of the cleats in kinematic, kinetic and neuromuscular variables has not been described so far in this population.

Apart from the risk of injury, performance is another frequent concern of the players (Hennig, 2011). The influence of the cleats on the performance has been studied over the years by several authors and all of them have chosen to evaluate healthy individuals (De Clercq et al., 2014; Hennig, Althoff, & Hoemme, 2009; McGhie & Ettema, 2013; Muller, Sterzing, Lange, & Milani, 2010; Sterzing & Hennig, 2008; Sterzing, Müller, Hennig, & Milani, 2009; Sterzing, Müller, & Milani, 2010; Sterzing, Müller, Wächtler, & Milani, 2011). Despite most of the studies assess sports performance during sprint or changes of direction manoeuvres (Clarke & Carré, 2010; De Clercq et al., 2014; McGhie & Ettema, 2013; Muller et al., 2010; Sterzing et al., 2009; Sterzing et al., 2010), other sports skills such as kicking velocity (Sterzing & Hennig, 2008) and accuracy (Hennig et al., 2009) and the ability to handling a ball (Sterzing et al., 2011) have been evaluated. In artificial grass, SG models seems to decrease sprint performance (Muller et al., 2010; Sterzing et al., 2009), while on wet ground the TF models provide the lowest performance (De Clercq et al., 2014). On the other hand, healthy players achieved increased performance with a cleat prototype specially designed for artificial grass (AG and FG models sole mixing) compared to all other commercialized models (Sterzing et al., 2009; Sterzing et al., 2010). Furthermore, specific cleat characteristics such as bladed studs improved performance compared with the elliptical ones in changes of direction (Sterzing et al., 2009; Sterzing et al., 2011), while models that allowed a more homogeneous pressure across the foot during ball contacts promoted a better accuracy of kicking (Hennig et al., 2009). Finally to achieved the maximum ball velocity the players benefit from cleats that promoted a better traction in the standing limb (Sterzing & Hennig, 2008). Despite all this knowledge gathered about the influence of cleats on the performance of healthy soccer players, no studies have been described in players with CAI (De Clercq et al., 2014; Hennig et al., 2009; McGhie & Ettema, 2013; Muller et al., 2010; Sterzing & Hennig, 2008; Sterzing et al., 2009; Sterzing et al., 2010; Sterzing et al., 2011).

Thereby, the medical staff and athletes should contemplate strategies to prevent sports related injuries, as well as strategies that improve athletes' performance to achieved the best sports results (Unlucan, 2014). This will allow players to provide the best possible spectacle to his fans, while improve their carriers duration/quality and clubs performance/prestige (Lees & Nolan, 1998). Thus, healthy players and especially those who present CAI will benefit from a specialized monitoring, based fundamentally on prevention methods (Kalirathinam et al., 2016; Karlsson, Verhagen, Beynnon, & Amendola, 2009; Martin et al., 2013; Schiftan, Ross, & Hahne, 2015), where the physiotherapist plays a determinant role (Bulley et al., 2004). Sports physiotherapists are specialists in human functional movement aiming to promote wellness, mobility and performance. Furthermore, they are specialized in prescribing therapeutic and prophylactic exercise in a structured, safe and effective way (Bulley et al., 2004). Their competencies areas may include be an innovator (research involvement), a professional leader (life-long learning), an advisor (promotion of a safe active lifestyle) and specially a manager of the athlete. In this last competence, they should intervene in (i) injuries prevention, (ii) acute intervention, (iii) rehabilitation and (iv) performance enhancement. Respecting the above order, from the sports physiotherapy point of view, health promotion should play a greater role in the sports amateur or professional context (Bulley et al., 2004). The socioeconomic impact of ankle sprain on health systems is enormous, once each injury can cost between 360,60 € to 10.949,00 €, which multiplied by the total number of injuries can exceed 234 million euros per year (Boer, Schepers, Panneman, Beeck, & Lieshout, 2014; Kemler et al., 2016). So, it makes sense to combine efforts to implement preventive programs/policies. Therefore, the simplest and most effective way that sports physiotherapist have for minimize this impact is to act on prevention (Bulley et al., 2004) by providing knowledge to athletes and coaches about modifiable risk factors. Of all risk factors, the cleat type and its suitability for artificial grass fields is one of the most easily modifiable, so the purpose of this PhD thesis is to identify the best model to prevent LAS while ensuring the necessary sports performance.

1.1 Main objectives

The key objectives defined for this PhD project were organised around two major concerns of soccer players: performance and injury risk. As such, the central objectives addressed can be stated as follows:

- to evaluate the cleats' influence on ankle sprain injury risk of healthy soccer players in artificial grass, with and without fatigue.

- to evaluate the cleats' influence on performance of soccer players with and without CAI in artificial grass.

- to evaluate the cleats' influence on ankle sprain injury risk of soccer players with and without CAI in artificial grass.

To assess the purposes above, musculoskeletal dynamics, expressed by kinematic, kinetic and electromyographic variables were investigated.

2. THESIS ORGANISATION

This PhD thesis is organized in six main topics that are structured in sections. Initially, the work developed will be described in a topic that translates the rationale between each article (section 3). Subsequently, several methodological options regarding the sample, the analysed biomechanical variables, and the functional tasks performed by the participants will be discussed (section 4). These methodological considerations are crucial to justify some methodological options that are not detailed in the articles. The following topic will present five journal articles selected for their contribution to the research objectives of this thesis (section 5). This topic is followed by an overall discussion of the results obtained on whole work undertaken (section 6). Finally, the main contributions achieved during this PhD thesis (section 7), as well as the main conclusions and future work perspectives are described (section 8).

3. DESCRIPTION OF THE WORK DEVELOPED

The soccer evolution, especially on playing fields and cleats, served as a guide for the elaboration of this thesis. The impact of these evolution on sports performance and injury risk defined the following steps. Therefore, five scientific articles were written. The thesis organization is summarized in the figure 1.

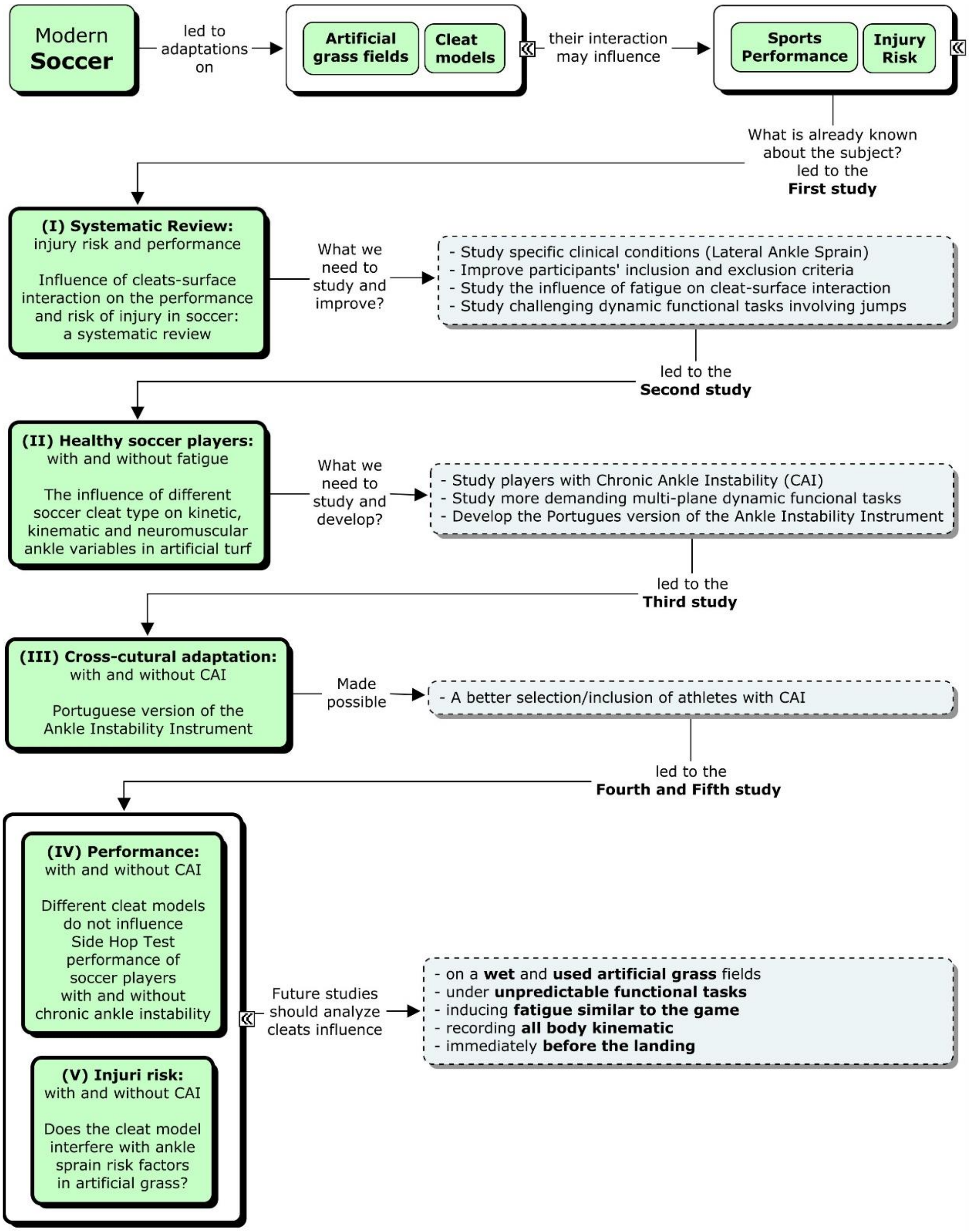

Figure 1: Thesis organization diagram

Our first study was a systematic review of literature, regarding the influence of different cleats on performance and injury risk in soccer. The need to compile and describe the state of the art on this topic was important to define the objectives and methodological strategies to be adopted in the experimental studies that followed. In our systematic review we analysed papers that compared cleats on natural and artificial grass, referring only to soccer, excluding those who analyse American football or rugby. Usually, studies evaluated the cleats by assessing healthy young adult athletes or by using mechanical instruments that simulated sports gestures. From this point on, it became clear the need to study variables related to specific sport and clinical conditions, as well as improving the sample inclusion and exclusion criteria. For this reason, we chose to develop a second study, this time with an experimental design. Although we have evaluated healthy players, we study variables related to a specific clinical condition - lateral ankle sprain.

The second study aimed to analyse the influence of different cleats on variables related to the risk of lateral ankle sprain. This study was innovative because it included a moment of evaluation under fatigue of the peroneal muscles. In addition to using a dynamic functional task, we have increased its difficulty by imposing the fatigue condition to approximate study conditions to what happens in the second half of a game. Considering the high prevalence of LAS (Fong et al., 2009; Garrick, 1977; Garrick & Requa, 1988) and CAI (Gerber, Williams, Scoville, Arciero, & Taylor, 1998) it has become relevant to extend this type of evaluation to the athletes with history of ankle sprains and CAI.

The criteria for the inclusion of patients/athletes with CAI in controlled research were described by the International Ankle Consortium (Gribble et al., 2014). Thus, the players must present history of at least one significant ankle sprain, associated with inflammatory symptoms; the initial sprain must have occurred at least 12 months prior to study enrolment; created at least 1 interrupted day of desired physical activity and the most recent injury must have occurred more than 3 months prior to study enrolment (Gribble et al., 2014). On the other hand, the players must refer history of the previously injured ankle joint ‘‘giving way’’ and/or recurrent sprain and/or ‘‘feelings of instability’’ (Gribble et al., 2014). Specifically, participants should report at least 2 episodes of giving way in the 6 months prior to study enrolment. Furthermore, self-reported ankle instability should be confirmed with a validated ankle instability specific questionnaire (Gribble et al., 2014). The currently recommended questionnaires englobe the Ankle Instability Instrument (AII), the Cumberland Ankle Instability Toll (CAIT) and the Identification of Functional Ankle Instability IdFAI (Gribble et al., 2014).

Our third study emerged with the purpose of improving the selection process of athletes with chronic instability for experimental studies on Portuguese speaking countries. Since the CAIT is already adapted to a Brazilian-Portuguese language (de Noronha, Refshauge, Kilbreath, & Figueiredo, 2008), it has proved to be appropriate to adapt another questionnaire, increasing the number of questionnaires that can be used in studies with Portuguese-speaking populations. Thus, we choose to develop the Portuguese version of the Ankle Instability Instrument (AII). The association between this questionnaire and the orthopaedic drawer test allowed the creation of two distinct groups of soccer players: with and without CAI. The creation of these groups was important to perceive the real influence of the cleat models on the two main concerns of the athletes: performance and injury risk.

In our systematic review we compiled several studies related to cleat influence on performance (Silva et al., 2017a), usually associating SG model with worse performances during sprints in a straight line or with changes of direction in artificial grass (Muller et al., 2010; Sterzing et al., 2009; Sterzing et al., 2010). However, none of these studies have described the cleats’ influence on performance of players with CAI. For this reason, our fourth study aimed to evaluate the sports performance on players with and without CAI to find the cleat model that best serves this purpose. Although performance is a key factor in this sport, for players, supporters, managers and coaches, from the point of view of a sports physiotherapist, the assessment of injury risk necessarily takes on greater importance.

Several authors have studied the risk of injury associated with different cleats (Silva et al., 2017a), but only a few studies have objectively reported considerations about a specific clinical conditions, such as calcaneal apophysitis (Walter & Ng, 2002) or metatarsalgias related to repeated impact injuries (Bentley et al., 2011; Queen et al., 2008; Smith et al., 2004). Most of the studies hypothesize about the possibility of non-specific injuries in the knee (Brock et al., 2014; Gehring et al., 2007; Kaila, 2007; Stefanyshyn et al., 2010) or ankle (Brock et al., 2014; Müller et al., 2010; Stefanyshyn et al., 2010; Villwock et al., 2009). On the other hand, our group have clearly proposed to assess the risk of a specific clinical conditions - ankle sprain - using variables related to risk factors during a dynamic task that mimics one of the injury mechanisms (Silva et al., 2017b). Thus, our fifth study aimed to evaluate the risk of lateral ankle sprain in players with and without CAI. The goal was to bring knowledge to health professionals, players and the entire sports community to act in prevention, encouraging the promotion of health in sports without compromising performance, but promoting it. However, some questions still need to be answered. In future studies, it will be important to replicate our experimental methodologies, exploring other artificial grass conditions, other functional tests and fatigue protocols, as well as a more complete kinematic analysis. The guidelines for future studies will be addressed in more detail in section 8 (conclusions and future work perspectives).

This section showed the work developed during this PhD project to address the main objectives defined. However, it makes sense to address some methodological options and discuss their justifications to later describe the articles produced.

4. METHODOLOGICAL CONSIDERATIONS

In all experimental research studies, decisions were taken regarding methodological parameters to assess the purposes established. As for the work carried out under this PhD thesis, some of these decisions were not fully justified in the articles. Such decisions are mainly related to the sample selection criteria, the selection of biomechanical variables and the functional task assessed. The rational are detailed in the following sub-sections.

4.1. Sample

The comparison of different cleat models can be done through mechanical simulation or through studies involving athletes (Silva et al., 2017a). The mechanical devices that simulate sports gestures have the advantage of consistently repeat the task between cleat models, reducing the variability between evaluations, frequently observed in studies with athletes (Silva et al., 2017b). However, several serious drawbacks are related to this method. First, they are only able to simulate part of the sport movement (Clarke & Carré, 2010; Livesay, Reda, & Nauman, 2006; Muller et al., 2010; Villwock et al., 2009). When the authors intend to conclude for example about the performance associated with a sprint, they can only evaluate the initial part of this gesture, the fixation of the foot to the ground at the initial instants of the start (Clarke & Carré, 2010; Muller et al., 2010). This detail leads to the second problem of these methodologies that are the variables used. Usually, they evaluate performance indirectly through traction indices/coefficients and hypothesize that this traction will be reflected in performance indicators (Clarke & Carré, 2010; Muller et al., 2010). However, they do not evaluate specific variables such as speed. Will these authors be able to guarantee that a certain cleat model associated to increased traction coefficients will increase the performance of the athlete or, on the other hand, may be perceived by them as potentially damaging and thus decrease performance? These disadvantages highlight the need to study athletes (Galbusera et al., 2013; Muller et al., 2010) even because the biological variability of each athlete can reveal surprisingly different results from those obtained through mechanical instruments (Sterzing, Müller, Schwanitz, Odenwald, & Milani, 2008). Thus, the need of studying real athletes rather than simulated gestures performed by a mechanical device became obvious.

On the other hand, the athlete's selection criteria adopted in previous studies compromise the interpretation of the results obtained. In fact, some authors defined their sample as healthy, based only on the absence of injury in the past 6 months (Butler et al., 2014; Queen et al., 2008) or simply did not reveal information about previous injuries (Müller et al., 2010; Muller et al., 2010; Smith et al., 2004; Sterzing et al., 2010; Walter & Ng, 2002). Considering the evidence that athletes can present chronic ankle instability, involving mechanical and/or functional deficits, in the following 3 years after an ankle sprain episode (Martin et al., 2013), it is questionable the designation of healthy for this group of athletes. To overcome this limitation, and supported by the high frequency of ankle sprains in soccer players (Fong et al., 2007; Kobayashi & Gamada, 2014; Ridder et al., 2015), we based our selection criteria on the guidelines stated by the International Ankle Consortium (Gribble et al., 2014). Thus, our sample of healthy athletes never had an ankle sprain (both feet) or other major lower limb injury, whereas the players with CAI had to present mechanical and functional instability and no other lower limb injuries. The combination of these two kinds of instability created a more homogeneous group with CAI, since these clinical conditions separately may lead to multiple subgroups of individuals with ankle instability (Hiller, Kilbreath, & Refshauge, 2011). Hiller (2011), hypothesized that depending on the impairment, participants with mechanical and functional instability may perform differently than those with only functional instability (Hiller et al., 2011). This author suggested 7 distinct subgroups in a new model: (I) Mechanical instability (MI); (II) Perceived instability (PI); (III) Recurrent sprains (RS); (IV) MI + PI; (V) PI + RS; (VI) MI + RS and (VII) MI + PI + RS (Hiller et al., 2011). However, the author assumed that this model requires further validation (Hiller et al., 2011). Three years later, the International Ankle Consortium determined that individuals with CAI should have history of at least one significant ankle sprain, but did not necessarily present recurrent sprains (Gribble et al., 2014). Thus, we decided to include athletes with both types of instability in the group with CAI, including those who had history of recurrent sprains or who only report one significant ankle sprain, if it was associated with inflammatory symptoms and created at least 1 interrupted day of desired physical activity (Gribble et al., 2014). Besides respecting epidemiological data, the evaluation of athletes with and without CAI gives the opportunity of evaluating cleat-surface interaction in athletes with and without postural control deregulation.

As already shown, an unilateral capsule-ligament injury may dictate bilateral deficits in postural control (Evans, Hertel, & Sebastianelli, 2004) and for that reason, we only considered players as healthy if they never have suffered any sprain in both feet. Consequently, to be part of the CAI group, the players should have only sprain one of their ankles (dominant foot). This detail, allows a stronger interpretation of the data by eliminating a possible bias.

Considering that the final goal of the present thesis is to contribute to injury prevention, we have stablished criteria to ensure the most representative population of soccer players. We have included only amateur male players because compared to professional athletes (200 thousand), amateurs players (240 million) represent the majority of practitioners (Valderrabano, Barg, Paul, Pagenstert, & Wiewiorski, 2014), and because the male athletes represent the majority of the soccer players (90%) (Kunz, 2007). Although the overall incidence ratio for ankle sprain did not differ between males and females, male athletes between 14 and 24 years old had a higher incidence rate (Waterman, Owens, Davey, Zacchilli, & Belmont, 2010). Still, we have included 18-30 years old athletes because they are experienced young adult players representative of the last level of the modality capable of a more consistent motor performance. Despite this, the mean age in our experimental studies ranged from 21-23 years old, being thus within the range that presents a higher risk, and which benefits from more attention.

In our first experimental study we chose to evaluate only players with *pes cavus* to guarantee sample homogeneity (Silva et al., 2017b). This option was based on the controversial influence of foot type on the incidence of ankle sprain and on the presence of CAI at the time of our first experimental study (Morrison

& Kaminski, 2007). On one hand, military recruits who were classified as having a low medial longitudinal arch suffered a significantly higher number of acute and recurrent LASs as compared with those with a high or normal arch height (Mei-Dan et al., 2005). On the other hand, higher arches were seen in the subjects operated due to CAI than in the matched controls (Larsen & Angermann, 1990). Despite this, in the following studies, we chose not to evaluate the foot type, since, in a recent systematic review and meta-analysis, the foot type does not appear as an intrinsic risk factor for LAS (Kobayashi, Tanaka, & Shida, 2016).

4.2. Biomechanical variables selected

All the variables analysed in the experimental studies, as well as the characteristics of the sample to be controlled were based on the established intrinsic and extrinsic risk factors for ankle sprain (Beynnon et al., 2002; Martin et al., 2013) (table 1).

Table 1 - Controlled and analysed variables related to injury risk

Potential risk factor for LAS	Controlled variables	Dependent variables	Independent variables
History of previous sprain, ligament laxity, age, gender, limb dominance, height, weight and body mass index, playing field, external support, sport modality, level of competition, participation in neuromuscular training, player position.	x		
Ankle range of motion, anatomic alignment		x	
Proprioception, Postural sway/Balance		x	
Muscular variables (magnitude and activation time)		x	
Footwear type, fatigue			x

Through the sample characterization questionnaire (Appendix III) and the inclusion/exclusion criteria used for both groups, it was possible to control potential risk factors for LAS, related to history of ankle sprain, physical characteristics as well as game features. However, in our experimental studies we chose not to subdivide the groups according to the player's position in the field. Although this risk factor is consensual in sports such as volleyball (players near the net), in soccer the increased risk does not seem to be so closely related to the position that the player habitually occupies in the field, but mainly when a player leaves his usual position in a specific move to other areas of the field that is not so accustomed (Karlsson et al., 2009). For example, when a defender incurs an offensive play (Karlsson et al., 2009). For that reasons and because a considerable part of our sample mentioned that usually plays in distinct positions, we not subdivide the sample considering the position that the player occupies in the field. The remaining risk factors were evaluated through dependent or independent variables.

The decrease of dorsiflexion range of movement has been described as predictor of LAS (Noronha, Refshauge, Herbert, & Kilbreath, 2006), and for that reason, we choose to evaluate and described this characteristic in both groups. On the other hand, considering inversion as the most common mechanism of injury (Martin et al., 2013; Richie, 2001), we evaluate the eversion/inversion range of movement through kinematic analysis. As the reflective markers manually fixed on the cleat could differ in the positioning, from model to model, we chose to evaluate the difference in amplitude between the maximum eversion and the maximum inversion, instead of analysing the inversion amplitude with the anatomical ankle neutral position as a reference. Our option was intended to reduce the error associated with the positioning of the markers on the cleat. On the other hand, the static anatomic alignment of the calcaneus was not registered before the experimental tests, however, its evaluation was implicit during eversion/inversion dynamic evaluation.

The variables that best describe an individual's proprioceptive competences are the kinaesthesia, the joint position sense and the sense of force (Riemann & Lephart, 2002), and are frequently assessed with the isokinetic dynamometer (Lin, Li, Tsai, & Liing, 2008; Sandrey & Kent, 2008; Willems, Witvrouw, Verstuyft, Vaes, & De Clercq, 2002). This instrument make impossible the evaluation of the cleat-surface interaction (Han, Waddington, Adams, Anson, & Liu, 2016). The usual procedures in this type of evaluations requires a barefoot condition, however if we chose to include the cleats it would be methodologically impossible to evaluate their interaction with the playing field in the isokinetic dynamometer.

Furthermore, all models are low-cut profile, keeping contact with the athlete's foot just below the ankle, thus making it difficult that these models could induce any influence on the results of those proprioceptive variables. On the other hand, the dependent variables we used for assessing postural sway/balance were based on the displacement of the Center of Pressure (COP). In fact, COP variables have been recurrently described in studies that intend to associate poor postural control to increased risk of LAS in healthy subjects and in those who suffer an acute LAS or presents CAI (McKeon & Hertel, 2008a). Furthermore, from all non-instrumented and instrumented measures of postural control in single-limb stance that have been reported in the ankle instability literature, the instrumented force plate measures became the gold standard. As a measure associated with force plates (McKeon & Hertel, 2008a), the COP is considered the center of distribution of the total force applied to the supporting surface and represents the weighted average of all pressures created from the area in contact with the support surface (Palmieri, Ingersoll, Stone, & Krause, 2002). Various parameters including mean sway amplitude, maximum sway amplitude, minimum sway amplitude, peak-to-peak amplitude, sway velocity etc. have been frequently studied (Duarte & Freitas, 2010; Palmieri et al., 2002). The peak-to-peak amplitude may not be the best option to represent the postural control in long static evaluations, because small perturbations in the environment (e.g. noise) that influences the postural control system could cause a loss balance for a split second and create a large than normal peak-to-peak amplitude (Palmieri et al., 2002). However, we chose to evaluate this variable because the task that our players performed was extremely fast, being important to record even the smallest COP displacement in that brief period (Huang, Lin, Kuo, & Liao, 2011). Based on the assumption that the different cleat models could possibly induce the same COP displacement, it was also important to evaluate the velocity of these displacement over time (Evans et al., 2004; Hertel, Buckley, & Denegar, 2001). If some cleat model increased COP velocity, it could indicate that this model were potentially worse for postural control (Palmieri et al., 2002). Another reason to study the COP velocity was based on the analyses of repeated measures that reveals this parameter as the most reliable (Salavati et al., 2009).

The integrated analysis of kinematic and kinetic parameters is essential for a global view of biomechanics surrounding a certain landing task (Niu, Feng, Wang, Jiang, & Zhang, 2016). Based on this assumption, the inclusion of kinetic variables in our experimental studies was extremely important, since they have been extensively used for the study of subjects with and without CAI during dynamic activities (Moisan, Descarreaux, & Cantin, 2017). Due to the easiness of its measurement and accuracy of results, variables such as vertical ground reaction force (GRF) are frequently used in the analysis of sports gestures as landing and in the study of prophylactic preventive methods for ankle injuries (Niu et al., 2016; Riemann, Schmitz, Gale, & McCaw, 2002). Furthermore, mediolateral GRF is frequently analysed in studies with similar objectives and in those who study sports gestures with changes of direction (Cloak, Galloway, & Wyon, 2010; Dayakidis & Boudolos, 2006; Sacco Ide et al., 2006). Thus, it has become important to study kinetic variables such as the mediolateral and vertical components of the GRF allowing the comprehension of the cleats' influence in postural control/balance and injury risk (Caulfield & Garrett, 2004; Dayakidis & Boudolos, 2006). In fact, despite being an indicator of the intensity of stress on the human system during ground contact (McClay et al., 1994), the risk of injury may potentially be even more so if the magnitude of loading rate is high (Ricard & Veatch, 1990). For this reason, in our experimental studies, we have analysed the vertical and mediolateral loading rates of the GRF.

Variables related to muscle strength such as slow eccentric inversion strength have been associated with significantly increased risk of LAS (Kobayashi et al., 2016). However, the evaluation of the force through dynamometers was not in agreement with our study objective (study the cleat-surface interaction). On the other hand, muscle activity assessed by surface electromyography (EMG) responds better to our purpose, since it allowed us to evaluate the cleat-surface interaction, providing information about the magnitude and activation time of the main lateral stabilizers of the ankle during inversion - the peroneal muscles. These two neuromuscular variables are extremely importance in the postural control and have been extensively studied in individuals with and without CAI (Feger, Donovan, Hart, & Hertel, 2015; Koldenhoven, Feger, Fraser, Saliba, &

Hertel, 2016; Lin, Chen, & Lin, 2011; Louwerens, Linge, de Klerk, Mulder, & Snijders, 1995; Moisan et al., 2017; Santilli et al., 2005). Although electromyographic magnitude is considered an indirect method for muscle strength evaluation, electromyography signal has the advantage of being able to evaluate activation time, which seems to be even more important than the force in the evaluation of the risk for LAS (Delahunt, 2007a).

On the other hand, our independent variable in all the experimental studies were the soccer cleats. Unlike some studies, which compared running sports shoes with soccer cleats (Brock et al., 2014; Butler et al., 2014; Stefanyshyn et al., 2010), in our studies we have selected only models that soccer players used in real practice or competitive conditions. Many other authors evaluated Soft ground cleat models with aluminium studs in artificial grass fields (Bentley et al., 2011; Galbusera et al., 2013; Müller et al., 2010; Muller et al., 2010; Stefanyshyn et al., 2010; Sterzing & Hennig, 2008; Sterzing et al., 2009; Sterzing et al., 2010), however the "*Norms and Instructions for Soccer*" - official federation document - prohibits their use in this type of fields (FPF, 2017). Therefore, we have not compared sports shoes of other modalities such as running shoes, neither cleats with studs that are prohibited in artificial grass fields. We believe that these methodologic options increased the ecologic value of our studies, making our conclusions more easily transferred to the real sport conditions.

Furthermore, fatigue of the peroneal muscles was also considered as an independent variable in the study of cleats' influence on the risk of LAS. Since, fatigue induced by general or local exercises contributes to deteriorate the postural control (Paillard, 2012), we chose to induce fatigue through local exercises with the aim of reducing the time spent in experimental procedures. Indeed, localized muscle fatigue induced by the repetition of voluntary muscular contractions at many locations like the ankle (or muscle groups) showed to be sufficient to disturb postural control (Paillard, 2012). Thus, several authors showed that a local muscular exercise lasting only a few minutes is likely to induce a deterioration of postural control when the maximum voluntary contraction loss is superior or equal to 30% (Paillard, 2012). Generally, there are three methods to induce localized fatigue: (i) producing a strength loss of a muscle group to a pre-stablished value (Bisson, McEwen, Lajoie, & Bilodeau, 2011; Bizid et al., 2009; Davidson, Madigan, Nussbaum, & Wojcik, 2009; Granacher, Gruber, Forderer, Strass, & Gollhofer, 2010; Singh, Nussbaum, & Madigan, 2009); (ii) repeating a number of pre-established simple segmental movements or maintaining isometric (or dynamic) muscular action during a certain time period (Reimer & Wikstrom, 2010; Strang, Berg, & Hieronymus, 2009; Walsh, Peper, Bierbaum, Karamanidis, & Arampatzis, 2011) or (iii) inducing an incapacity to continue a particular exercise consisting of isometric or dynamic contractions (Berger, Regueme, & Forestier, 2010; Laudani, Wood, Casabona, Giuffrida, & De Vito, 2009; Thedon, Mandrick, Foissac, Mottet, & Perrey, 2011; Wojcik, Nussbaum, Lin, Shibata, & Madigan, 2011). The second method could induce distinct levels of fatigue in athletes with different sports capabilities since it has as reference the time of exercise. The third could be too demanding and eventually lead to a possible LAS during the functional task because it turns out to be a maximal exercise. Thus, we opted for the first method as it ensures a homogeneous level of fatigue among the participants. The strength losses in this type of protocol varies between 5% and 70% (Paillard, 2012). We opted for 50% for being above the 30% defined as the minimum necessary to cause deficits in postural control and for being below the maximum limit that could be too demanding. Since fatigue appears to potentiate the risk of injury (Lin et al., 2008; Sandrey & Kent, 2008), we have chosen to submit only healthy athletes to this experimental condition. Athletes with CAI usually present a higher risk of injury (Delahunt, Monaghan, & Caulfield, 2006; Koshino et al., 2014; Terada, Pietrosimone, & Gribble, 2014) and would be ethically reprehensible to subject them to a potentially damaging experimental condition given their functional impairments.

Finally, the principal variable used in our study concerning the influence of the soccer cleat on sports performance was the time to finish the functional task. In fact, this is the most used variable in similar studies (De Clercq et al., 2014; Muller et al., 2010; Sterzing et al., 2009; Sterzing et al., 2010). Additionally, we also studied the distance travelled by the athlete’s foot, as well as their average speed as performance indicators. These two variables can add relevant information when analysing the results. Thus, if the athlete takes the same time to finish the task with different cleat models, we can see if he has covered a longer course in the same time interval, or if his average speed has been higher with a given model, considering it as an enhancer of sports performance.

4.3. Functional task

Functional-performance tests should be considered as dynamic measures of general assessment of lower limb function. These tests are extremely important in the clinical and sports context, since they combine multiple components such as muscle strength, neuromuscular coordination and joint stability that can be affected after joint injury (Docherty, Arnold, Gansneder, Hurwitz, & Gieck, 2005).

In our experimental studies, we have selected dynamic functional tasks because they: (i) seem to be a more demanding alternative than the single-foot static positioning tests, widely used in the posture control assessment (Delahunt, 2007a), (ii) have been already demonstrated to be able to detect functional deficits amongst individuals with and without ankle instability (Caffrey, Docherty, Schrader, & Klossner, 2009; Docherty et al., 2005) and (iii) comprehend changes of direction with jumps that are closely related to sport gesture associated with higher risk for LAS (Martin et al., 2013). For this purpose, we selected and adapted two functional tests: Side Hop Test and 6-meter Crossover Test. In fact, these tests proved to be easily adaptable to study the cleats' influence, both on variables related to the risk of LAS and on variables related to performance.

In the injury risk evaluation, we have used the Side Hop Test first, which presumes mediolateral displacements in the frontal plane, and evolve to a more demanding test, the 6-meter Crossover Test, which is characterized by displacements in both frontal plane and sagittal plane. To avoid data misinterpretation, we used the metronome to standardize the execution speed of the test. Otherwise, factors such as motivation could possibly induce the execution of the test at different speeds with different cleat models, influencing the kinematic, kinetic or neuromuscular values. The velocity defined for each test was based on the maximum average velocity performed by individuals during pilot tests similar to those included in our sample.

On the other hand, the metronome was not used in the evaluation of cleats' influence on the performance, being asked the participants to execute the Side Hop Test as faster as possible. While some authors record their execution time through hand-held stopwatch (Docherty et al., 2005), we chose to optimize this procedure making it more accurate using force plates. Thus, the laboratorial constraints inherent to the force plates location only allowed the performance evaluation through the Side Hop Test and this was the main reason why we didn't assess performance through the 6-meter Crossover Test.

5. ACCEPTED AND SUBMITTED ARTICLES

First, a systematic review will be presented regarding the influence of the cleats on the performance and risk of injury in soccer. The second article refers to the cleats' influence in healthy soccer players on the risk of LAS, with and without fatigue. The study that follows, aimed to culturally and linguistically adapt the self-reported questionnaire (AII) to facilitate the later studies of soccer players with CAI. Subsequently, the fourth and fifth studies evaluated the cleats' influence in soccer players with and without CAI, in terms of performance and risk of LAS, respectively. All articles are fully described in this section. The numbering of tables and figures will be restarted with each article.

<u>Article I</u> - Influence of cleats-surface interaction on the performance and risk of injury in soccer: a systematic review

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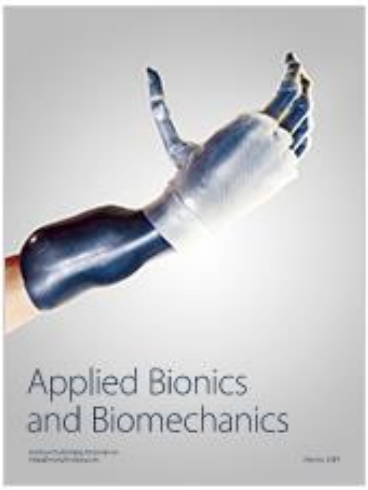
Journal:



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ABSTRACT

Objective. To review the influence of cleats-surface interaction on the performance and risk of injury in soccer athletes. Design. Systematic review. Data Sources. Scopus, Web of science, PubMed, and B-on. Eligibility Criteria. Full experimental and original papers, written in English that studied the influence of soccer cleats on sports performance and injury risk in artificial or natural grass. Results. Twenty-three articles were included in this review: nine related to performance and fourteen to injury risk. On artificial grass, the Soft ground model on dry and wet conditions and the turf model in wet conditions are related to worse performance. Compared to rounded studs, bladed ones improve performance during changes of directions in both natural and synthetic grass. Cleat models presenting better traction on the stance leg improve ball velocity while those presenting a homogeneous pressure across the foot promote better kicking accuracy. Bladed studs can be considered less secure by increasing plantar pressure on lateral border. The Turf model decreases peak plantar pressure compared to other studded models. Conclusion. The Soft ground model provides lower performance especially in artificial grass, while the Turf model provides a high protective effect in both fields.

Keywords: Performance; Injury risk; Studs; Artificial grass; Natural grass

Key Points:

- On artificial grass, the Soft ground model is related to a decreased athlete's performance;

- On wet conditions, the Turf model is related to decreased performance;

- The Turf model provides higher protection against the risk of injury.

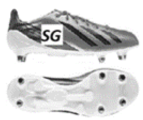
1. Introduction

Soccer is the most practiced and most popular sport worldwide (Kunz, 2007). This sport is followed by millions of people around the globe, mobilizing people to the stadium, to watching games on TV/internet, and to listen via radio. Its popularity turned it into an industry where the sports scores and goals achieved are of the utmost importance (Unlucan, 2014). Therefore, the importance of this sport supports the need of looking for strategies to improve athletes' performance, but also to prevent sports related injuries. This will allow players to provide the best possible spectacle to his fans, while improve their carriers and clubs (Lees & Nolan, 1998).

Several adaptations have been introduced in soccer along the years. The increasing use of artificial grass field (FIFA, 2009, 2012) and changes in format and materials used in soccer cleats are examples of this adaptation (Conenello, 2010; Sterzing, 2016). These changes agree with the increased importance attributed to the cleat-surface interaction in both performance and the injury risk. The adequacy of soccer footwear to the kind of field seems to have a determinant role in both (Hennig, 2011; Kulessa et al., 2017; McPoil, 2000; Sterzing, 2016). Several research studies have been developed regarding this area. However, there is no broad consensus as to the adequacy of the kind of the cleat to the respective field to fulfil the requirements of performance and injuries risk. The different study methodologies and the funding from shoe or turf companies can possible contribute to this divergence (Clarke & Carré, 2010; Galbusera et al., 2013; McGhie & Ettema, 2013; Muller et al., 2010; Queen et al., 2008; Sterzing et al., 2009; Sterzing et al., 2010; Villwock et al., 2009). The lack of consensus in this topic has been recently demonstrated in a qualitative review (Kulessa et al., 2017). The authors didn't conclude about the best cleat to reduce the injury risk and to improve performance. Inside of this the authors have made several conclusions as to general aspects of shoe surface interaction. This difficulty can be based on the large variability of sports modality englobed in the review (Kulessa et al., 2017). Because each modality has a specific sports gestures, that impose different demands on cleat-surface interaction, as well as different rules, each sports modality should be considered separately (Gabbett, 2005; Hogarth, Burkett, & McKean, 2016; Lees & Nolan, 1998).

The cleats have been considered the most important soccer tool, playing a crucial role in the athletes' performance (McPoil, 2000; Sterzing, 2016). Its structure can be divided in two main parts, the upper portion, composed by leather or synthetic material, and the sole. The structure of the sole depends on the pitch and is adjusted to provide a good contact with the ground. The studs should provide enough traction to prevent slipping or sliding, which can result in overstretch or tear injuries, but should facilitate sudden change of directions (Conenello, 2010). The distribution pattern and geometry of studs vary widely between models and manufacturers (Lees & Nolan, 1998). Currently there are basically five types of soles: Turf (TF), Artificial grass (AG), Hard Ground (HG), Firm Ground (FG) and Soft Ground (SG) (Conenello, 2010; Queen et al., 2008). According to the manufactures, the TF and AG models are suitable for artificial fields and HG model for hard natural or dirt soccer fields. The FG model is indicated for natural grass in good conditions, while the SG to very muddy or wet natural fields. The classification of these models depends on the size, number, distribution and type of studs. Thus, the first model (TF) presents the highest number of studs, but also the smaller ones. The other models present a progressive decrease in the number of studs and an increase in its size (Queen et al., 2008). Normally, the SG model is characterized by rigid plastic soles and only six aluminium studs. In the TF model, the sole and studs are usually composed by rubber while the AG, HG and FG models present rigid soles and studs, usually made of plastic (Conenello, 2010). Another feature that varies constantly is the stud geometry (cylindrical, conical, prismatic and bladed) (Clarke & Carré, 2010) and for this reason, several studies have questioned if the increased traction promoted by bladed studs improves performance during sudden changes of direction or, on the contrary, could increase the risk of injury (Bentley et al., 2011; McGhie & Ettema, 2013; Muller et al., 2010; Queen et al., 2008; Sterzing et al., 2009; Sterzing et al., 2010; Villwock et al., 2009). The cleats' characteristics are summarized in Table 1.

Table 1 - Cleats' characteristics

Cleat model		*Indicated field*	*Studs/sole material*	*Studs*		
				Number	*Size*	*Geometry*
	Turf	Synthetic	Rubber studs and compliant sole	>55	6-7 mm	Cylindrical, conical (rounded), prismatic and bladed
	Artificial grass		Plastic studs and rigid plastic sole	22	8-10 mm	
	Hard ground	Dirt field		14	10-12 mm	
	Firm ground	Natural ground in good conditions		11	10-12 mm	
	Soft ground	Muddy or wet natural ground	Aluminium studs and rigid plastic sole	6	13-16 mm	

With the increasing number of models available on the market, it becomes important to review the influence of cleat-surface interaction on athletes' performance and injury risk to identify the cleat that better responds to the need of increased performance and reduced injury risk.

2. Methods

2.1 Research question

The two main research questions in this study were:

1- Which model of soccer cleats promotes a better performance in artificial and natural grass?
2- Which model of soccer decreases the risk of injury in artificial and natural grass?

2.2 Search strategy

The literature search included only the period from 2000 until 2016 on the following databases: Scopus, Web of science, PubMed and B-on (table 2).

The following search terms combinations were used in all databases: soccer shoes; soccer boots; soccer cleats; soccer studs; soccer footwear; shoe-surface interface and shoe-surface interaction. The search terms were limited to titles and abstracts published in academic journals. The reference lists of all studies were also scanned to identify other potential eligible articles. The study was conducted using the systematic review method proposed by the Preferred Reporting Items for Systematic Reviews and Meta-Analysis – PRISMA (Moher, Liberati, Tetzlaff, & Altman, 2009). The articles included in this review were as follows: (i) experimental and original papers, written in English; (ii) studied soccer cleats influence on sports performance in artificial or natural grass; iii) studied soccer cleats influence on injury risk in artificial or natural grass; (iv) compared more than one cleat model in sport tasks; (v) analysed young and adult soccer players or used mechanical devices; and (vi) studied soccer players of both genders and all competitive levels. Review articles and those that studied, rugby or American football cleats were excluded because the technical gesture and the rules of this sport differ significantly from soccer.

Table 2 – Number of papers collected from different databases

Search terms	Scopus	Web of science	PubMed	B-on
Soccer shoes Soccer boots Soccer cleats Soccer studs Soccer footwear Shoe-surface interface Shoe-surface interaction	66	44	34	59

2.3 Assessment of methodologic quality

The studies included in this systematic review were evaluated using a quality index proposed by Downs and Black (Downs & Black, 1998) and the recommendations of Munn et al. (Munn, Sullivan, & Schneiders, 2010). Studies meeting <60% criteria were considered low quality, 60%–74.9% moderate quality, and >75% high quality. Each author independently performed the quality assessment for each of the included studies. Consensus regarding the quality index score for each study was agreed upon by both authors.

2.4 Data extraction

Data from the included studies was extracted by one reviewer and then checked by a second reviewer using a data extraction table which identified the following: author identification, year of publication, sample, ground and footwear conditions, methods and instruments, variables assessed and main conclusions regarding the cleat-surface interaction on performance and injury risk.

3. Results

The search strategy revealed 213 articles. After an initial review, 84 were rejected as copies of the same paper and 95 were excluded as they were clearly unrelated with the main theme or because the sport studied was not soccer. All remaining articles were then reviewed by two independent reviewers. Consensus was reached and a total of 23 were included as shown in Figure 1. Nine of them were related to performance and fourteen with injury risk.

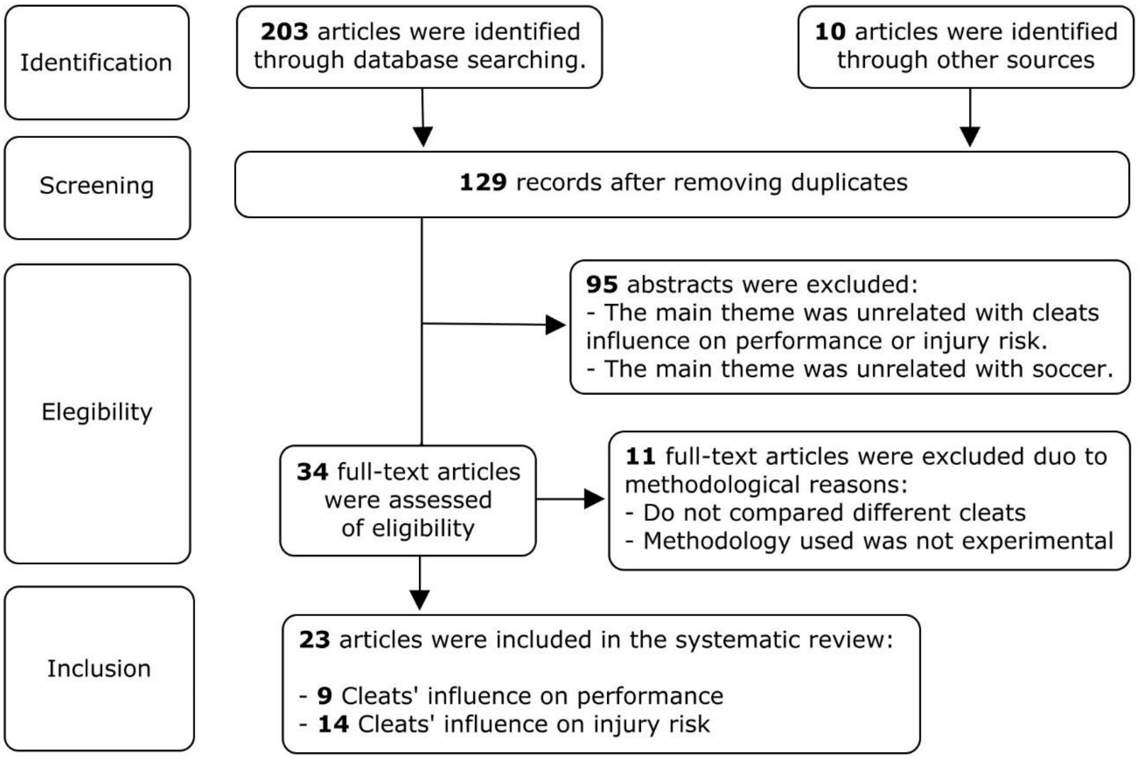


Figure 1: Study selection and inclusion criteria

3.1 Study design and sample - cleat-surface interaction on Performance

Most of the studies assessed the traction imposed by different cleat models during sprint or change of direction manoeuvres (Clarke & Carré, 2010; De Clercq et al., 2014; McGhie & Ettema, 2013; Muller et al., 2010; Sterzing et al., 2009; Sterzing et al., 2010). Some studies evaluated other sport performance components, such as kicking velocity (Sterzing & Hennig, 2008) and accuracy (Hennig et al., 2009) and the ability to handling a ball (Sterzing et al., 2011). With the exception of two studies that evaluated the cleats on natural and artificial fields (Clarke & Carré, 2010; Sterzing et al., 2009), the majority included artificial grass field in their set up (De Clercq et al., 2014; McGhie & Ettema, 2013; Muller et al., 2010; Sterzing & Hennig, 2008; Sterzing et al., 2010; Sterzing et al., 2011). The authors that have evaluated the kicking accuracy didn’t provide information regarding the kind of field in which the tests were performed (Hennig et al., 2009). Only one study based the results on mechanical simulations (Clarke & Carré, 2010). All other studies obtained their results from experienced male soccer players. The sample size ranged from 12 to 52 athletes, with age ranging between 16 and 25 years, the body weight between 67 to 77,5 Kg and height between 176 and 181 cm (De Clercq et al., 2014; Hennig et al., 2009; McGhie & Ettema, 2013; Muller et al., 2010; Sterzing & Hennig, 2008; Sterzing et al., 2009; Sterzing et al., 2010; Sterzing et al., 2011). In Table 3 are synthetized the main features of the studies described.

Table 3 - Studies regarding the cleat-surface interaction on performance

Author year	*Sample*	*Ground and Cleat type*	*Methods and instruments*	*Variables*	*Conclusions*	*Quality index score (%)*
(Sterzing & Hennig, 2008)	20 male experienced soccer players: 25,4 ± 3,3 years 75,1 ± 7,1 Kg 177,6 ± 5,3 cm.	***Ground***: (i) Artificial grass ***Footwear condition***: (i) FG (0%, 50%,100% stud length) (ii) SG (100% stud length) (iii) Own soccer shoe (iv) Two premium cleat models	***Tasks***: 6 maximum kicks per shoe condition. ***Instruments***: (i) Stalker Pro radar gun (ii) Force platform.	(i) Peak ball velocity, (ii) Perceived ball velocity, (iii) Peak resultant shear force of the stance leg	Traction in the standing limb is partly influenced by the stud height, which in turn influences the kicking movement and ball velocity. The shoe weight and outsole stiffness had any effect on resultant ball velocity. Different shoe models alter the resultant ball velocity.	56,25%
(Sterzing et al., 2009)	52 male amateur or sub-elite soccer players: 24,5 ± 4,2 years 73,2 ± 7,0 Kg 177,9 ± 4,8 cm divided by 8 studies.	***Ground***: (i) Dry and wet Artificial grass (ii) Dry and snow Natural grass ***Footwear condition***: (i) HG (ii) FG rounded and bladed (iii) SG (iv) FG (0% stud length) (v) FG (50% stud length)	***Tasks***: (i) Straight line sprints. (ii) Slalom. ***Instruments***: (i) Photovoltaic cells.	(i) Running time (ii) Running time perception (given by a cleat ranking).	SG cleats with high studs' worse performance in synthetic. The behavior of the cleats on dry and wet ground was similar. Bladed studs improve performance compared with the elliptical ones in the slalom test, under dry and ice/snow conditions. Performance was gradually reduced with the reduction of stud height (50% and 0% of its original size). The increase of 70 g in shoes and the heel contour comfort doesn't seem to interfere with performance. The model defined by the manufacturers as indicated for synthetic turf favored performance compared to design model for natural grass and it was perceived by athletes.	59,38%

(Hennig et al., 2009)	(i) 1st study – 24 male subjects. (ii) 2nd study- 20 male subjects.	***Ground***: (i) not mentioned ***Footwear condition***: 1st study - Five different shoe modifications 2nd study - Two shoes with significantly different accuracy in the 1st study	***Tasks***: (i) 20 repetitive inside and instep kicks towards a target. ***Instruments***: (i) Circular electronic target (ii) Plantar pressure insoles	(i) Mean ball deviation (cm) from the target (ii) Pressure distribution pattern.	Although most soccer players are not aware of it, kicking speed and accuracy can be influenced by footwear design.	31,25%
(Clarke & Carré, 2010)	A mechanical testing device was used instead of a soccer player sample.	***Ground***: (i) Artificial grass (ii) Natural grass ***Footwear conditions***: (i) Six models of cleats with different studs' dimensions and geometry.	***Tasks***: (i) Three trials of simulated sprints start. ***Instruments***: (i) Mechanical testing device with hydraulic system.	(i) Penetration capacity (ii) Horizontal traction force.	In natural grass, only highest and cylindrical studs not fully penetrate, which may explain the lack of traction. The conical studs demonstrate better penetration. The average horizontal traction increases with the studs' cross-sectional area, but the opposite happens if the stud not fully penetrate. Comparing two models of conical studs, in artificial turf, the lowest showed higher traction.	59,38%
(Muller et al., 2010)	25 male sub-elite soccer players: 22,9 ± 4,1 years 71,5 ± 6,3 Kg 177,9 ± 4 cm. A mechanical device was used to simulate sprints starts.	***Ground***: (i) Artificial grass ***Footwear conditions***: (i) HG (ii) FG (iii) SG (iv) Prototype	***Tasks***: (i) Straight line sprints. (ii) Slalom. (iii) 45° and 180° changes of direction. (iv) Simulation of sprints starts. ***Instruments***: (i) Photovoltaic cells (ii) Force platform (iii) Mechanical traction device.	(i) Running time and their perception (ii) Peak vertical force (iIi) Vertical force rate (iv) Peak shear force (v) Shear force rate (vi) Coefficient of traction.	Athletes present worse performance with SG model compared to other models. The SG seems unable to fully penetrate into the artificial grass causing instability mechanisms.	56,25%

(Sterzing et al., 2010)	47 male experienced soccer players: 23,0 ± 3,2 years 71,4 ± 5,9 Kg 177,3 ± 4,4 cm divided in 3 phases of the study.	***Ground***: (i) Artificial grass ***Footwear conditions***: (i) HG (ii) FG (iii) SG (iv) Prototype (v) 4 variations of prototype	***Tasks***: (i) Straight line sprints. (ii) Slalom. (iii) 45° and 180° changes of direction. ***Instruments***: (i) Photovoltaic cells (ii) Force platform.	(i) Running time and their perception (ii) Traction suitability perception (iii) Peak vertical force (iv) Peak a-p and m-l shear force (v) Peak resultant shear force (vi) Perceived ratios	The sole of the cleat developed was proved to be more suitable for synthetic compared to the 3 already commercialized models. Shoes with high studs (SG) do not seem to be the most suitable for artificial grass.	71,88%
(Sterzing et al., 2011)	19 male experienced soccer players: 24,0 ± 3,6 years 72,1 ± 3,1 Kg 178,3 ± 1,9 cm.	***Ground***: (i) Artificial grass ***Footwear conditions***: (i) FG rounded (ii) FG bladed	***Tasks***: (i) Dribbling (ii) One touch passes of rolling balls, (iii) Lofted passes, (iv) Reception passes (v) Passes from aerial (vi) Juggling. ***Instruments***: (i) 0-10mm scale for handling suitability perception	(i) Ball handling suitability (ii) Dribbling (time and ball contacts) (iii) Juggling (ball contacts) (iv) Passes (cm).	Dribbling: FG bladed showed faster dribbling times compared to FG rounded model. Passes: No differences were found between footwear conditions.	59,38%
(McGhie & Ettema, 2013)	22 male soccer players: 23,1 ± 2,8 years 77,5 ± 6,0 Kg 1,81 ± 0,1 m.	***Ground***: (i) 3 different Artificial grass field heights: (42; 50; 60mm) ***Footwear conditions***: (i) TF (ii) FG rounded (iii) FG bladed	***Tasks***: (i) 5 short sprints with a 90°change of direction. ***Instruments***: (i) Force platform (ii) Motion capture system (iii) Photovoltaic cameras	(i) Peak impact (ii) Traction (iii) Total change in velocity (iv) Sliding velocity traction coefficient	The traction coefficient appears to be homogeneous as regards different combinations of cleats-ground, suggesting that individuals can adjust the gesture so as to maintain the desired level of traction in the task of changing direction.	71,88%

(De Clercq et al., 2014)	12 male soccer players: 16 ± 1 years 67,3 ± 8,1 Kg 1,76 ± 8,8 m.	***<u>Ground</u>***: (i) Dry and wet Artificial grass ***<u>Footwear conditions</u>***: (i) TF (ii) AG (iii) FG	***<u>Tasks</u>***: (i) 10 x 5 shuttle run tests with a 180°change of direction. ***<u>Instruments</u>***: (i) Force platform (ii) Perception of performance questionnaire.	(i) Traction (ii) Time to finish the shuttle run test (iii) Players perception.	Players perceived small differences in performance and traction. On dry artificial grass, the three tested stud designs do not affect performance or traction. On wet condition, the TF showed a larger shuttle run time. AG and FG fulfil the traction needs in both conditions.	62,50%

3.1.1 Synthesis of the results - cleat-surface interaction on Performance

The findings obtained in artificial grass, showed that generally SG models decrease performance (Muller et al., 2010; Sterzing et al., 2009), however on wet ground, the TF provides the lowest performance (De Clercq et al., 2014). The results obtained with a specific cleat prototype for artificial grass englobing sole characteristics from the AG and FG models favoured performance compared to all other commercialized models (Sterzing et al., 2009; Sterzing et al., 2010).

The studies that have addressed specific cleat characteristics demonstrated the following: (i) bladed studs improved performance compared with the elliptical ones (Sterzing et al., 2009; Sterzing et al., 2011); (ii) increased stud height seems to improve performance (Sterzing et al., 2009), since the studs can fully penetrate (Clarke & Carré, 2010); (iii) models that allowed a more homogeneous pressure across the foot during ball contacts promoted a better accuracy of kicking (Hennig et al., 2009); (iv) the cleat weight or heel comfort seem not interfere with performance (Sterzing et al., 2009); and (v) the maximum ball velocity was achieved with cleats that promoted a better traction in the standing limb (Sterzing & Hennig, 2008). However, players can adjust the sport gesture to maintain the desired level of traction in sport tasks (McGhie & Ettema, 2013).

3.2 Study design and sample – cleat-surface interaction on Injury risk

Most of the studies stated their conclusion based on dynamic tasks like straight running (Bentley et al., 2011; Smith et al., 2004; Walter & Ng, 2002), slalom (Bentley et al., 2011), cutting and turning manoeuvres (Brock et al., 2014; Gehring et al., 2007; Kaila, 2007; Müller et al., 2010; Queen et al., 2008; Stefanyshyn et al., 2010). Only the three most recent studies have incorporated jump (Butler et al., 2014) or landing tasks with changes of direction (Brock et al., 2014; Silva et al., 2017b). Four studies based their conclusions on peak torque and the translation or rotational stiffness assessed from mechanical simulations (Galbusera et al., 2013; Livesay et al., 2006; Stefanyshyn et al., 2010; Villwock et al., 2009). The other studies based their conclusions on plantar pressures

(Bentley et al., 2011; Queen et al., 2008; Walter & Ng, 2002), the ankle or knee range of movement (Brock et al., 2014; Butler et al., 2014; Müller et al., 2010; Silva et al., 2017b; Walter & Ng, 2002), the ground reaction forces (Brock et al., 2014; Butler et al., 2014; Gehring et al., 2007; Kaila, 2007; Müller et al., 2010; Silva et al., 2017b; Smith et al., 2004), and neuromuscular variables (Gehring et al., 2007; Silva et al., 2017b) collected from soccer players. Nine articles analysed the cleats on artificial grass (Bentley et al., 2011; Brock et al., 2014; Butler et al., 2014; Gehring et al., 2007; Kaila, 2007; Müller et al., 2010; Queen et al., 2008; Silva et al., 2017b; Stefanyshyn et al., 2010), one on natural grass (Smith et al., 2004), three on both fields (Galbusera et al., 2013; Livesay et al., 2006; Villwock et al., 2009) and one didn't provide this information (Walter & Ng, 2002). This last study was the only that assessed young players. The majority of the studies relied on experienced male (Bentley et al., 2011; Brock et al., 2014; Gehring et al., 2007; Kaila, 2007; Müller et al., 2010; Silva et al., 2017b; Smith et al., 2004; Stefanyshyn et al., 2010) and both gender (Butler et al., 2014; Queen et al., 2008) soccer players. The sample size ranged from 6 to 36 athletes, with age ranging between 8 and 26 years, the body weight between 64 to 85 Kg and height between 168 and 183 cm. In Table 4 are compiled the main features of the studies described.

Table 4 - Studies regarding the cleat-surface interaction on injury risk

Author year	*Sample*	*Ground and Cleat Type*	*Methods and instruments*	*Variables*	*Conclusions*	*Quality index score (%)*
(Walter & Ng, 2002)	36 male children: 8 to 11 years.	***Ground***: (i) Not specified ***Footwear condition***: (i) Cleats with studs (ii) Cleats without studs	***Tasks***: (i) A straight run. ***Instruments:*** (i) Plantar pressure insoles (ii) High speed video.	(i) Length of time from heel strike to heel lift (ii) Ankle dorsiflexion angle (iii) Plantar pressure distribution.	The use of cleats with studs imposes a significant increase in dorsiflexion, which increases pressure on the growth center of the calcaneus. The high incidence of calcaneal apophysitis and the use of shoes with cleats in young populations might be related.	34,38%
(Smith et al., 2004)	6 male soccer players: 25 ± 4,18 years 79,7 ± 9,32 Kg.	***Ground***: (i) Natural grass ***Footwear condition***: (i) TF (ii) SG	***Tasks***: (i) A straight line slow (4,4m/s) and fast running (5,4 m/s). ***Instruments***: (i) Force platform.	(i) Impact peak and loading rate (ii) Maximal breaking and propulsion forces (iii) Maximal medial and lateral forces.	The aluminium cleats impose increased vertical forces and loading rates being consequently probably more associated with repeated impacts injuries. Its use in hard grounds seems to be not advised.	43,75%
(Livesay et al., 2006)	A mechanical testing device was used instead of a soccer player sample.	***Ground***: (i) Natural grass (ii) 4 different artificial grass fields ***Footwear condition***: (i) TF (ii) FG	***Tasks***: (i) Mimic a change-of direction maneuver under a compressive load of 333N. ***Instruments***: (i) Mechanical testing device	(i) Peak torque (ii) Rotational stiffness.	The highest peak torques were developed by the FG model on the FieldTurf tray, and by the TF model on Astroturf field combinations. The lowest peak torques were developed on natural grass field.	65,63%

(Kaila, 2007)	15 male soccer players: 19,5 ± 1,4 years 70,1 ± 7,6 Kg 1,76 ± 0,06 m.	***Ground***: (i) Artificial grass ***Footwear condition***: (i) 2 FG rounded (ii) 2 FG bladed	***Tasks***: (i) Straight-ahead run (ii) 30° and 60° sidestep cutting. ***Instruments***: (i) Motion capture system (ii) Force platform.	(i) Internal/external tibia moments (ii) Valgus/varus moments (iii) Anterior/posterior joint forces (iv) Knee flexion angles (v) Vertical ground reaction forces.	Different cleat type showed no difference on knee loading for each maneuver.	68,75%
(Gehring et al., 2007)	6 male soccer players: 25,2 ± 1,4 years 77,8 ± 8,3 Kg 183,2 ± 3,4 cm.	***Ground***: (i) Artificial grass ***Footwear condition***: (i) FG rounded (ii) FG bladed	***Tasks***: (i) A 180° turning movement. ***Instruments***: (i) Motion capture system (ii) Force platform (iii) EMG recorder.	(i) Maximum ground reaction force (Fz, Fx, Fy) (ii) Peak EMG activity (quadriceps/ hamstrings) (iii) Knee joint moments (flexion/extension)	Round and bladed studs showed no differences in externally applied knee joint loads. Higher activation of quadriceps femoris with round studs was showed during initial phase of stance.	62,50%
(Queen et al., 2008)	36 soccer players: 20,83 ± 3,05 years 71,12 ± 10,38 Kg 1,71 ± 0,08 m (19 males and 17 females).	***Ground***: (i) Artificial grass ***Footwear condition***: (i) TF (ii) HG (iii) FG rounded (iv) FG bladed	***Tasks***: (i) running with side cut (ii) Change of direction of 180°. ***Instruments***: (i) Plantar pressure insoles.	(i) Total time contact (ii) The contact area (iii) Maximum strength (iv) Peak pressure (v) Force time integral of the medial region, middle and side of the forefoot.	In changing the direction of 180° and run with side cut, the foot peak pressure was significantly lower with the TF model compared with all others in both gender. Force time integral of the lateral forefoot region was higher on the Bladed model, compared to the TF model in the males. In males, the total area of contact was significantly lower in the FG model compared to the TF model. In the female, the force time integral and the medial forefoot maximum force was significantly lower with the TF model compared to all others.	78,13%

(Villwock et al., 2009)	A mechanical testing device was used instead of a soccer player sample.	***Ground***: (i) 2 natural grass (ii) 2 artificial grass ***Footwear condition***: 10 different models: (i) 4 (rounded studs) (ii) 3 (Bladed studs) (iii) 2 (replaceable studs) (iv) 1 TF	***Tasks***: (i) Mobile testing apparatus was used to apply rotations at the shoe-surface interface. ***Instruments***: (i) Mechanical testing device.	(i) Maximum torque (ii) Rotational stiffness.	Artificial grass fields showed increased rotational traction compared to natural grass which may lead to higher risk of injury. Maximum torque and rotational stiffness were not influenced by the studs' pattern. More malleable construction of the upper shoe can allow greater pronation during leg internal rotation. This can increase the probability of tibioperoneal rupture.	71,88%
(Stefanyshyn et al., 2010)	12 soccer players: 26,4 ± 6,2 years 74,0 ± 7,4 Kg 176,4 ± 4,1 cm. A mechanical testing device was also used.	***Ground***: (i) Artificial grass ***Footwear condition***: (i) Running shoe (ii) FG rounded (iii) SG rounded (iv) SG bladed	***Tasks***: (i) Cutting and turning movements at 4,0 ms^{-1}. (ii) Translational traction: (iii) Rotational traction: ***Instruments***: (i) Mechanical testing device (ii) Force platform (iii) Motion capture system.	(i) Ankle joint moments: plantar/flexion; external rotation; eversion. (ii) Knee joint moments: extension; external rotation; abduction (iii) Translational (iv) Rotational traction.	Cutting movement: no significant differences in resultant ankle and knee joint moments between the shoe conditions. Turning movement: the FG (round), SG (round) and SG (bladed) had higher ankle and knee rotation moments than the running shoe. An increased rotational traction increases ankle and knee joint loading which in turn could potentiate a higher incidence of injury.	56,25%
(Müller et al., 2010)	15 soccer players: 20,7 ± 2,8 years 71,6 ± 5,4 Kg 176,3 ± 5,6 cm.	***Ground***: (i) Artificial grass ***Footwear condition***: (i) Cleat with studs completely removed (ii) Prototype (iii) FG (iv) SG	***Tasks***: (i) 135° turning movement. ***Instruments***: (i) Motion capture system (ii) Force platform.	(i) Peak force (Fz, a-p) (ii) Foot angles (iii) Shank angles (iv) Foot translation (v) Maximum ankle and knee moments.	Movement patterns for turning in different cleats were influenced by stud configuration and were primary found in the distal part of the lower extremities. Soccer players showed reduced medio-lateral foot translation and increased ankle moments due to high and unsuitable traction. Cleats with studs completely removed (low traction) lead to movement adaptations in response to an increased risk of slipping.	62,50%

(Bentley et al., 2011)	29 male amateur soccer players. Without anthropometric data of the sample.	***Ground***: (i) Artificial grass ***Footwear condition***: (i) SG rounded (ii) SG bladed	***Tasks***: (i) Straight run (ii) Slalom. ***Instruments***: (i) Plantar pressure insoles	(i) Peak pressure (ii) Pressure-time integral over 11 clinically relevant areas of the foot.	The model with rounded studs can be considered more secure since it features normal pressure distributions while the model with bladed studs is potentially more harmful once it reveals increased pressures on the lateral border of the foot.	68,75%
(Galbusera et al., 2013)	A mechanical testing device was used instead of a soccer player sample.	***Ground***: (i) Artificial grass (ii) Natural grass ***Footwear condition***: (i) FG rounded (ii) FG bladed (iii) SG rounded	***Tasks***: (i) Static preload of 1000 N and a rotation speed of 45°s^{-1} until a rotation of 140° was reached. ***Instruments***: (i) Mechanical testing device.	(i) Peak torque (ii) Rotational stiffness.	Stiffness values were smaller on natural compared to synthetic field. No differences were found between models with bladed studs and those with rounded studs. This study does not confirm the hypothesis that blade-shaped cleats may be more associated with increased risk of non-contact injuries.	65,63%
(Brock et al., 2014)	14 soccer players: 20,1 ± 1,4 years, 85,6 ± 9,7 Kg 1,81 ± 0,04 m.	***Ground***: (i) Artificial grass ***Footwear condition***: (i) Running shoe (ii) Cleats with artificial grass studs (iii) Cleats with natural studs	***Tasks***: (i) 180° cut (ii) Single-leg 90° land-cut ***Instruments***: (i) Motion capture system (ii) Force platform.	(i) Peak vertical and medial ground reaction forces (ii) Vertical loading rate (iii) Ankle and knee kinematic (range of movement, peak velocity and peak angle)	Few differences in ground reaction forces or kinematic variables were observed between the shoe conditions. However, during 180° cut movement, natural grass studs produced the lowest peak medial ground reaction forces compared to other two models.	81,25%

(Butler et al., 2014)	28 soccer players - <u>14 males</u>: 22,1 ± 3,9 years 73,3 ± 11,5 Kg 1,77 ± 0,66 m. - <u>14 females</u> 22,8 ± 3,1 years 64,4 ± 9,2 Kg 1,68 ± 0,07 m.	***<u>Ground</u>***: (i) Artificial grass ***<u>Footwear condition</u>***: (i) Running shoe (ii) TF (iii) FG bladed	***<u>Tasks</u>***: (i) Header of a ball. ***<u>Instruments</u>***: (i) Motion capture system (ii) Force platform.	(i) Peak dorsiflexion angle (ii) Peak plantarflexion moment (iii) Peak knee flexion angle (iv) Peak knee extension moment (v) Peak hip flexion and extension moment (vi) Peak vertical ground reaction force.	Male soccer players exhibited an increased dorsiflexion with the bladed cleat compared to the running shoes or TF model. Female soccer players exhibited a reduction in peak knee flexion with the bladed cleat condition. The more rigid shoes seem to impair the female reception mechanism.	81,25%
(Silva et al., 2017b)	28 male soccer players without ankle sprain history: 23,13 ± 1,9 years 68,36 ± 5,20 Kg 1,76 ± 0,06 m. All players presented *pes cavus*.	***<u>Ground</u>***: (i) Artificial grass ***<u>Footwear condition</u>***: (i) TF (ii) HG (iii) FG	***<u>Tasks</u>***: (i) Five consecutive lateral jumps at a cadence of 120 beats per minute. ***<u>Instruments</u>***: (i) Pressure platform (ii) Force platforms (iii) Motion capture system (iv) EMG system (v) Isokinetic dynamometer.	(i) Ankle eversion/inversion range of movement (ii) Loading rate of the vertical and lateral force (iii) Lateral and rearward displacement and speed of the COP (iv) Activation time of the long and short peroneals.	In heathy soccer players, the contributor variables for ankle sprain were not influenced by the TF, HG and FG cleats. The conclusions were similar even after an evertor-oriented fatigue protocol.	81,25%

3.2.1 Synthesis of the results – cleat-surface interaction on Injury risk

In artificial grass, the TF model seems to be the best choice to prevent injuries related to repetitive impacts, when compared to FG and HG (Queen et al., 2008), and probably to reduce the risk of ankle and knee injury in turning movements, when compared to FG and SG models (Stefanyshyn et al., 2010). The increased risk of injury with FG and SG models seem to be explained by an increased and unsuitable traction promoted by these cleats (Müller et al., 2010). On another hand and surprisingly, the lower peak of medial ground reaction force demonstrated in SG model when compared with artificial grass studs seem to favour the use of this model (Brock et al., 2014). Furthermore, when more specific related injury risk variables were studied (ankle sprain), no differences were observed between different models of cleats (TF, HG and FG), even after an evertor-oriented fatigue protocol (Silva et al., 2017b).

The studies that have addressed specific cleat characteristics demonstrated the following: (i) the use of cleats without studs (similar to TF model) when compared to cleats with studs, could decreased the incidence of calcaneal apophysitis (Walter & Ng, 2002) and (ii) bladed studs revealed an increased risk of injury related to higher pressure on the lateral border of the foot when compared to rounded studs (Bentley et al., 2011) and impaired female reception mechanism after a jump (Butler et al., 2014), but no differences were observed in knee loading (Gehring et al., 2007; Kaila, 2007; Stefanyshyn et al., 2010) or in peak torque measured by a mechanical device (Galbusera et al., 2013).

Once again, in natural grass fields, the TF model revealed as the best choice when compared to SG model to prevent injuries related to repetitive impacts (Smith et al., 2004). Lastly, like it was stated for the performance, the kind of field has an important role in injury risk. When natural and artificial grass was compared, the last one showed a higher peak torque (Livesay et al., 2006), rotational traction (Villwock et al., 2009) and stiffness (Galbusera et al., 2013) evaluated by a mechanical testing device.

4. Discussion

4.1 Research question 1 - How cleat-surface interaction affects the performance?

Since 2008, Sterzing and co-workers evaluated various cleats models in two different fields (natural and artificial grass) during different functional tasks like slalom and short straight line acceleration (De Clercq et al., 2014; McGhie & Ettema, 2013; Muller et al., 2010; Sterzing et al., 2009; Sterzing et al., 2010), kicking (Hennig et al., 2009; Sterzing & Hennig, 2008), passing or handling a ball (Sterzing et al., 2011).

In general, the model defined by the manufacturers as indicated for artificial grass has been demonstrated to favour performance in this kind of field compared to design model for natural grass (SG) and this is perceived by athletes (Muller et al., 2010; Sterzing et al., 2009). The same studies revealed that SG cleats decrease performance in dry or wet artificial grass comparing to the other models probably because this model seems unable to fully penetrate into this ground, causing instability mechanisms (Muller et al., 2010; Sterzing et al., 2010). Globally the athletes' performance seems to be worsened when the stud height is reduced on dry conditions (Sterzing et al., 2009), but also on wet conditions, due to a lack of traction (De Clercq et al., 2014). The studs' geometry seems to be an influent factor in performance between different models of cleats. Bladed studs allowed better performance compared with the elliptical in slalom tests (Sterzing et al., 2009) and dribbling (Sterzing et al., 2011). The bladed shape of these studs and his orientation to the front may lead to increased traction in mediolateral manoeuvres and this could explain these results. It has also been demonstrated that studs with larger cross section area (not fully penetrated) provide decreased traction and because of that could provide decreased performance (Clarke & Carré, 2010). Finally, a prototype cleats' sole, similar to a regular FG outsole at the rearfoot, but with multiple double cylindrical thermoplastic polyurethane elastomers stud elements (DuoCell Techonology) at the forefoot was demonstrated to be more suitable for artificial fields, compared to three already commercialized models to natural fields (Sterzing et al., 2010).

In terms of performance, this prototype enabled the manufacturers to reflect about the ideal model for this type of field.

Studies performed on natural grass revealed that, despite not being perceived by the athletes, bladed studs are associated to increased performance compared to the elliptical ones in dry or ice and snow conditions (Sterzing et al., 2009). In this kind of field, the heel contour comfort and weight don't seem to interfere with the performance, at least in short performance tests (Sterzing & Hennig, 2008; Sterzing et al., 2009). However, we don't know if these two characteristics interfere with the performance in real game conditions. In this sense, further studies are required on this topic. Later studies have concluded that in natural grass, only cylindrical and highest studs not fully penetrate the field, which may explain the lack of traction. For this purpose, the conical studs provide better results (Clarke & Carré, 2010). Having a lower cross section area, this last stud geometry could have a major role in the degree of cleats penetration on natural grass.

Other performance tests regarding kicking tasks revealed that cleats that promote a good traction on the support leg, appear to enhance the speed of the shot, while outsole stiffness doesn´t contribute to increased kick velocity (Sterzing & Hennig, 2008). The stability of the support leg should be highlighted, since it seems to be a key point to improve the performance of the shot. Also, pass assertiveness can be positively influenced by the cleat presenting a more homogeneous pressure distribution between the upper shoe part and the ball (Hennig et al., 2009). Furthermore the dribbling capacity and velocity appears to be enhanced by FG bladed model compared to FG round model (Sterzing et al., 2011), may be because the slalom velocity inherent to this task is improved by bladed studs compared to the rounded ones (Sterzing et al., 2009).

Artificial grass feature numerous characteristics, such as infill particle size, level of compaction and fiber type, however only few characteristics have been considered in most of the papers (Clarke & Carré, 2010; Sterzing et al., 2009; Villwock et al., 2009). Some of these characteristics have been demonstrated to influence the athletes performance (McGhie & Ettema, 2013). McGhie and

Ettema (McGhie & Ettema, 2013) evaluated three models of cleats in three artificial grass conditions and have concluded that the pitch with smaller size of artificial grass and less rubber fill imposes more traction than the others. The dry or wet state of the artificial grass is another feature that influences performance. In wet conditions, the running time was increased with the TF model in relation to AG and FG models. The smaller studs founded in the TF model, decreases their traction and therefore their performance (De Clercq et al., 2014). The research about this theme has increased along time, especially in artificial grass supporting the growing incentive by FIFA for the use of this type of ground (FIFA, 2009, 2012).

Despite the high ability of athletes to compensate the different mechanical traction imposed by different cleats during a dynamic task, the findings obtained by the previously mentioned studies (Table 3) demonstrate that the cleat characteristics, together with the kind of field, can determine the effort required for a given performance (Muller et al., 2010). In fact, the studies mentioned in this review indicate that SG cleats impair performance, especially on artificial grounds. This model presents high studs and it doesn’t always allow their full penetration in the field, making traction difficult and worsening the execution of functional speed tests (Clarke & Carré, 2010; Muller et al., 2010; Sterzing et al., 2009; Sterzing et al., 2010). Concerning the studs’ geometry, the bladed models could improve performance, compared with the round studs, in slalom movements, whether in dry ground or with ice/snow. This particular model seems to increase the mediolateral traction facilitating this type of changes of direction (Sterzing et al., 2009). Also, no differences seem to exist between the TF, HG and FG models in terms of performance (McGhie & Ettema, 2013; Muller et al., 2010; Sterzing et al., 2009; Sterzing et al., 2010), unless the artificial grass is wet, which imposes decreased shuttle run test performance with the TF model (De Clercq et al., 2014). However, these results should be considered with caution, since performance was evaluated only in heathy subjects trough velocity in sprints, diverging just in the direction, straight or with direction shifts to 45°, 90° and 180°, as well as slalom sprint (De Clercq et al., 2014; McGhie & Ettema, 2013; Muller et al., 2010; Sterzing et al., 2009; Sterzing et al., 2010). None of the studies adopted functional tests closer to sport modality, like jumps with sprints that can be influenced by the type of footwear and ground (Butler et al., 2014). It should be noted that most of the studies have included male and young adult athletes from lower divisions, or amateurs (De Clercq et al., 2014; Hennig et al., 2009; McGhie & Ettema, 2013; Muller et al., 2010; Sterzing et al., 2009; Sterzing et al., 2010). Given the increasing popularity of this sport among women, it makes sense to extend this kind of studies also to this population.

4.2 Research question 2 - How cleat-surface interaction affects the injury risk?

Various cleats models have been evaluated since 2002 in both natural and artificial fields during different functional tasks (straight running, slalom, cutting and turning manoeuvres and landing after jumps). Unlike in the previous research question, this interaction was investigated not only in male athletes (Bentley et al., 2011; Brock et al., 2014; Butler et al., 2014; Gehring et al., 2007; Kaila, 2007; Müller et al., 2010; Queen et al., 2008; Silva et al., 2017b; Smith et al., 2004; Stefanyshyn et al., 2010), but also in female adults (Butler et al., 2014; Queen et al., 2008) and young athletes (Walter & Ng, 2002). On the other hand, to answer the present research question some articles used mechanical instruments (Galbusera et al., 2013; Livesay et al., 2006; Stefanyshyn et al., 2010; Villwock et al., 2009).

For a better understanding the results will be discussed considering the variables/instruments used to measure the injury risk of the different cleats models. First of all, it is important to highlight that most of authors used more than one instrument, combining, frequently, the use of motion cameras systems and force platforms (Brock et al., 2014; Butler et al., 2014; Gehring et al., 2007; Kaila, 2007; Müller et al., 2010; Silva et al., 2017b; Stefanyshyn et al., 2010). Whether on natural or on artificial fields, it has been demonstrated that adult players using aluminium studs (SG) present an increased vertical ground reaction forces which could be associated with injuries caused by repeated impacts (Müller et al., 2010; Smith et al., 2004). These findings seem not support the use of SG in hard grounds. The TF model presenting increased compliance (Conenello, 2010), seems to be more indicated to prevent this kind of injuries (Smith et al., 2004). Furthermore, cleats with removed studs increase the risk of slipping whereas the SG sole configuration with aluminium studs induce high loads on the player (Müller et al., 2010). However, surprisingly, during 180º cut movements in artificial grass, aluminium studs seem to produce the lowest peak medial ground reaction forces compared to artificial grass studs and non-studded running shoe (Brock et al., 2014). These findings could be related to the insufficient penetration showed by this model in artificial grass that could have induced a feeling of instability (Clarke & Carré, 2010; Muller et al., 2010) and led players to perform the task slowly. Apparently, there are no major differences between the TF, HG and FG models regarding kinetic (loading rate of ground reaction forces) and kinematic data (eversion/inversion range of movement, COP displacement and velocity) following jump with changes of direction. This is true even when the players were under a fatigue protocol for the main lateral ankle stabilizers. This conclusion must be considered carefully, since the fatigue protocol was applied to a small and specific muscle group of the ankle and the sample was composed by healthy athletes (without ankle sprain history). The nonexistence of differences could be due to the great capacity of healthy athletes to compensate small differences between models (Silva et al., 2017b). Additionally, during running, and cutting manoeuvres, no differences in ankle (Stefanyshyn et al., 2010) and knee (Gehring et al., 2007; Kaila, 2007) joint moments between FG (rounded and bladed) and SG models (rounded and bladed) were showed. Nevertheless, the rounded FG model when compared with the bladed FG, appears to potentiate the quadriceps femoris activation, which can be associated with an increased internal load on the anterior cruciate ligament (Gehring et al., 2007). This finding should be interpreted with caution because of the small sample size. Lastly, it should be noted that, the only study that assessed a pure jump task showed that more rigid shoes (bladed cleats compared to the running shoes or TF model) seem to impair the landing mechanism both in male and female players. Special attention should be given to this finding since female players presents increased risk of lower limb injury (Butler et al., 2014). A study involving young soccer population demonstrated that cleats with studs lead to a significant increase in dorsiflexion during the middle phase of support while running and a consequent increased pressure on the growth center of the calcaneus. Therefore, the high incidence of calcaneal apophysitis and the use of shoes with studs in young populations might be related (Walter & Ng, 2002). This article has a great importance because it encourages the young soccer players to make the best choices regarding the choice of footwear for different fields. In the education process of the athletes, it makes sense to start with the youngest.

Plantar pressure distribution and neuromuscular variables could give important insights regarding the risk of injury. However, few studies have addressed these variables. The TF model appears to be the only cleat that decreases the force and pressure beneath the metatarsal heads and, for that reason, could possibly minimize metatarsal injury risk (Queen et al., 2008). The bladed studs imposes increased plantar pressure on the lateral border of the shoe, while the model with rounded studs can be considered more secure since it leads to pressure distributions that mimic the normal plantar pressure profile (Bentley et al., 2011). Neuromuscular variables, such as activation time, were addressed in one study only. Despite its importance for the risk of injury assessment, no differences were observed in the peroneal activation time between TF, HG and FG models, even under fatigue. These results should be considered with caution since it can be questioned if the isolated fatigue of the peroneal muscles could be sufficient to impair the postural control mechanisms (Silva et al., 2017b).

Some authors encouraged the study of cleat-surface interaction using sporting gestures performed in place of practice/game (Lake, 2000), however, some interesting findings were obtained with mechanical simulations (Galbusera et al., 2013; Livesay et al., 2006; Stefanyshyn et al., 2010; Villwock et al., 2009). Galbusera et al. (2013), revealed no differences on rotational stiffness between the bladed and other two cleat models with rounded studs. Thus, could be exaggerated to suggest that athletes must reject the bladed models, since they do not seem to increase the risk of non-contact injury (Galbusera et al., 2013). However, because the material(s) used to construct the upper part of the shoe may influence rotational stiffness, future studies should explore this hypothesis (Villwock et al., 2009).

Like in performance, the kind of grass also influences the risk of injury. When peak torque and the rotational stiffness was assessed by a mechanical instrument in different fields, the lowest peak torque was related to natural fields compared to four different artificial fields (Livesay et al., 2006). In addition, it has been argued that the grounds seem to be more important than the cleats in traction, linking again, the artificial grass to a higher risk of injury (Hennig, 2011; Villwock et al., 2009).

In the future, it will be important to assess functional tasks and variables related to specific injuries in populations with higher risk, such as athletes with chronic ankle instability. Future studies involving jump strategies associated with different clinical conditions, like chronic ankle instability, are required, since the landing mechanism is a moment where a lot of injuries happen (Butler et al., 2014). If possible, the fatigue protocols imposed to athletes should be closer to the reality of the game (Silva et al., 2017b). The methodological quality of studies in this area should also continue to be improved.

Globally, the mentioned studies highlight the TF as a protective model and the SG as a potentially harmful model for repetitive impacts lesions, mainly in artificial fields. This is valid both in young (Walter & Ng, 2002) and adults players (Queen et al., 2008; Smith et al., 2004). When comparing the studs' geometry of the round aluminium studs and the bladed ones, the second model seems to boost the injury risk from the lateral border of the plantar surface (Bentley et al., 2011). It is still important to note that when comparing two fields (natural vs artificial) the second appears to potentiate injuries due to their rigidity (Livesay et al., 2006; Villwock et al., 2009).

5. Conclusion

Cleat-surface interaction is an important and current topic, not only because it interferes with one of the soccer players' concerns (performance), but also with the injury risk and absenteeism from sport practice. Literature reveals a decreased sports performance with the SG model, a protective feature of the TF model cleat, and an increased risk of injury in the artificial grass. However, the health promotion literature continues to be slightly specific. The study of this interaction in healthy subjects under fatigue is essential, but very little has been studied so far. Also, because soccer players present a high prevalence of ankle sprains, the cleat-surface interaction should be evaluated in athletes with increased risk of ankle sprain, such those with chronic ankle instability. Finally, another important factor is the introduction of dynamic and unpredictable test protocols for detection of differences in the cleat-surface interaction. The study of this interaction in the injury risk is an exciting field, but there is still much to explore. The results obtained about this topic will help sports health professionals to work more efficiently on injury prevention with the sports community.

<u>Article II</u> - The influence of different soccer cleat type on kinetic, kinematic and neuromuscular ankle variables in artificial turf

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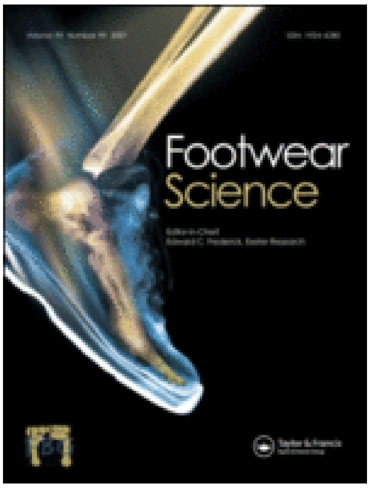

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ABSTRACT

Lateral ankle sprain is the most prevalent injury in soccer athletes. Enhanced by the variety of soccer cleats and by increased use of artificial turf, the interaction between the ground and the footwear has taken high importance as a lateral ankle sprain risk factor. The higher incidence of injuries in the second half of the match reflects the need of studying this interaction during tasks involving muscle fatigue. To evaluate the influence of different soccer cleats on kinetic, kinematic and neuromuscular ankle variables in artificial turf under two conditions: with and without fatigue of lateral ankle dynamic stabilizers. Study design: Experimental study within-subjects design. Twenty-four healthy athletes participated in this study. All subjects performed three sets of five mediolateral unipodal jumps, each one with one of three models of cleats (Turf, Hard and Firm ground) on two conditions: with and without fatigue induced by the isokinetic dynamometer. The electromyographic activity of long and short peroneal heads, ground reaction forces and the movement of the rear-foot were collected and used to calculate kinematic (ankle eversion/inversion, center of pressure displacement and velocity), kinetic (loading rate of the ground reaction forces) and neuromuscular variables (activation time of peroneal muscles). With the exception of decreased peroneal activation time with the Hard ground model (without fatigue vs. with fatigue), no statistically significant differences were identified in the ankle variables, between cleats, neither between the two evaluated conditions. In healthy soccer athletes, the contributor variables for ankle sprain were not influenced by the kind of soccer cleat in a functional test on a third-generation artificial turf.

Keywords: lateral ankle sprain, cleats, soccer, artificial turf, fatigue.

1. Introduction

With over 265 million athletes, soccer is the most played sport in the world (Kunz, 2007). Involving running with direction shifts, rotations, sudden stops and multiple jumps (Dubin, Comeau, McClelland, Dubin, & Ferrel, 2011), soccer is associated with a high prevalence of ankle sprain (Fong et al., 2007; Waterman et al., 2010). Ankle sprains account for 80-85% of all ankle injuries and 77-80% of them affect the lateral ligaments (lateral ankle sprain (LAS)) (Fong et al., 2009; Garrick, 1977; Garrick & Requa, 1988). Amongst amateur players, its incidence is about 2,16/1000 h of exposure (Kofotolis, Kellis, & Vlachopoulos, 2007), being more frequent during match periods (11,68/1000 h of exposure) (Fong et al., 2007).The combination of excessive inversion or supination and plantar flexion, while having an external rotation force applied on the leg have been traditionally described as the main lesion mechanism (Richie, 2001). More recent studies have demonstrated a trend of sudden ankle inversion but not plantarflexion (Mok et al., 2011).

Despite the lack of consensus in some variables, several intrinsic risk factors for LAS have been described: anthropometric data (taller and heavier athletes); ankle ligament instability; dominant limb (Beynnon et al., 2002); decreased dorsiflexion (Noronha et al., 2006); female gender (Doherty et al., 2014); ankle alignment deformities (calcaneal varus); type of foot (cavus) (Morrison & Kaminski, 2007); increased center of pressure (COP) displacement (McKeon & Hertel, 2008a; Munn et al., 2010); decreased evertor strength (Arnold, Linens, Motte, & Ross, 2009), increased peroneal muscular activation time (Beynnon et al., 2002) and previous sprain history (Pourkazemi et al., 2014). Although not normally included in the intrinsic risk factors, fatigue should be studied due to its influence on joint position sense (Bisson et al., 2011; Jackson, Gutierrez, & Kaminski, 2009; Lin et al., 2008). In fact, several authors demonstrated that fatigue can lead to a predisposition for injury, affecting the joint-position sense that could reduce the capability to jump landing with the foot in an appropriate position (Lin et al., 2008; Sandrey & Kent, 2008). Changes on afferent muscles' discharge patterns, due to metabolic acidosis, may reduce the responsiveness of the Golgi tendon organs and muscle spindles, thus originating proprioceptive deficits, increased activation time, decreased muscular strength and postural stability (Hiemstra, Lo, & Fowler, 2001). In terms of extrinsic risk factors, the increased traction index between the footwear and the playing field has been described as the most relevant for the LAS (Hennig, 2011; Lake, 2000).

Over the past few years, an increasing implementation of 3rd generation synthetic turfs have been observed, mainly amongst amateur clubs. The Fédération Internationale de Football Association (FIFA) has encouraged such an implementation due to the turf's durability, the low maintenance cost and the ability to withstand a high number of playing hours, regardless of weather conditions (FIFA, 2009, 2012). Currently, sporting footwear manufacturers offer various options for synthetic turfs. Amongst all the characteristic properties of this type of footwear, the two considered most important by athletes are stability of the foot in the shoe and good traction on the field (Hennig, 2011; Kinchington, Ball, & Naughton, 2011). The component that has the major influence in fulfilling the last requirement is the sole of the footwear (Sterzing et al., 2010). There are mainly three sole models allowed on synthetic fields: Turf; Hard ground and Firm ground (figure 1).

Figure 1: Cleat models used in the present study

Despite all models can be used in synthetic fields, some manufacturers recommend the use of the first model for synthetic turf, the second model to either hard natural and synthetic turfs, and the last one for normal natural turfs (Queen et al., 2008). However, the footwear selection is not usually based on this recommendation, as the Firm ground and Hard ground models are frequently used on synthetic playing fields (Sterzing et al., 2010). This fact may be the reason behind a higher frequency of LAS in 3rd generation synthetic turfs when compared to natural turfs (Ekstrand, Timpka, & Hägglund, 2006). However, it should be noted that there is not an absolute consensus about this epidemiological factor, as other studies haven´t identify significant differences in injury frequency between these two types of playing field (Aoki et al., 2010; Ekstrand, Hagglund, & Fuller, 2011).

Considering the exponential increase on the number of synthetic turfs, the different cleats options and the high frequency of LAS in soccer players, especially on the second half of matches (Hawkins & Fuller, 1999; Tsiganos et al., 2007), it becomes relevant to analyze the type of cleats that best suit the synthetic turf, as a means to minimize the high injury rates. This study aims to evaluate the influence of the soccer shoe models on kinetic, kinematic and neuromuscular ankle variables in artificial turf, with or without fatigue of lateral ankle dynamic stabilizers. Specifically, this study aims to evaluate the influence of soccer shoe models in kinematic variables (ankle eversion/inversion range of movement); loading rate of vertical and lateral components of the ground's reaction forces (GRF); COP displacement-related variables and neuromuscular variables (activation time of the peroneals). Despite the lack of evidence, we thought that increased values in these variables could be associated to higher ankle instability and a consequent increased risk of ankle sprain.

2. Methods

2.1. Participants

Twenty-four male soccer players with at least five consecutive years of official competition and aged between 18 and 30 years participated in this study (age=23,13±1,90 years, height= 1,76±0,06 m, weight= 68,36±5,20 kg; mean ± SD). Only male athletes were included since the risk of ankle sprain is different in males and females (Doherty et al., 2014). The following exclusion criteria were defined: previous ankle sprain history, the presence of another neurological, muscular or skeleton injury (less than 1 year ago) of the lower limbs, history of lower limb surgery history, balance disturbances, neuropathies or other pathologies that affect posture control, as well as athletes that were under the influence of local anesthetics (McKeon, Booi, Branam, Johnson, & Mattacola, 2010). To guarantee sample homogeneity as to foot type, six individuals with flat foot soles were excluded. All participants presented pes cavus.

Most participants have between 11 and 15 years of official soccer practice (67%) and a training period of 7 - 8 h per week in the current season (79%).

The study was conducted according to the ethical norms of the Institutions involved and conformed to the Declaration of Helsinki, with informed consent from all participants.

2.2. Instruments

To characterize the sample as to the type of foot (cavus, normal and flat) a pressure platform *Emed*® model a-50 (*Novel*, 964 Grand Avenue St) with an acquiring frequency of 50 Hz was used (Paul, U.S.A.). This platform has a sensor area of 389 x 226 (mm) and a 2 sensors/cm^2 resolution and presents an excellent intra-observer reliability (ICC=0,975) in the determination of the foot arch index (Akins, Keenan, Sell, Abt, & Lephart, 2012). The calculation of the *Cavanagh index,* as an indicator of the type of foot, was made using a foot characterization *software* (Oliveira, Sousa, Santos, & Tavares, 2012).

To gather and analyze the ankle eversion/inversion movement amplitude, the *Qualisys motion capture*® system was used, with 4 cameras (*Oqus* 1) with an acquiring frequency of 100 Hz (*Qualisys AB*, Packhusgatan 6 S-411 13 *Gothenburg* Sweden) and 19 mm reflector markers. Although we use a 3D image capture system, the range of motion was analyzed only in the frontal plane. The instrument present an excellent intra-observer reliability (ICC = 0,90) for this plane (Sinclair et al., 2012).

The GRF signal was collected with a *Bertec*® FP4060-10 force platform connected to a AM 6300 amplifier (*Bertec Corporation*, 6171 Huntley Road Suite J Columbus, OH 43229 U.S.A.), connected to the *Qualisys motion capture*®

system. In jump assessment, the instrument shows an excellent intra-observer reliability (ICC between 0,92 – 0,98) (Hori et al., 2009). The platform was covered with a 3rd generation synthetic turf rug (2 m^2), composed of polyethylene fibers that are 60 – 65mm high and filled with purified silica and rubber. Its installation was assured by specialized technicians, with the platform being later calibrated.

The electromyographic signal (EMG) of the peroneal muscles was monitored using a bioPLUX research wireless signal acquisition system (Plux Ltda, Portugal). The signals were collected at a sampling frequency of 1000 Hz and were pre-amplified in each electrode and then fed into a differential amplifier with an adjustable gain setting (25 - 500 Hz; common-mode rejection ratio: 110 dB at 50 Hz, input impedance of 100 MΩ and gain of 1000). Self-adhesive silver chloride EMG electrodes were used in a bipolar configuration and with a distance of 20 mm between detection surface centers (Dahlhausen®, Köln, Germany). The skin impedance was measured with an Electrode Impedance Checker (Noraxon USA, Inc.). While determining the peroneus longus (PL) and peroneus brevis (PB) muscles' activation time, the EMG signal shows an excellent intra-observer reliability (ICC between 0,82 – 0,91) (Hopper, Allison, Fernandes, O'Sullivan, & Wharton, 1998).

To control the jump speed, an on-line digital metronome was used (www.metronomeonline.com).

In the process of fatigue induction on the ankle evertors, the *Biodex®System 4* (*Biodex* Medical Systems, Inc. 20 Ramsey Road Shirley, New York) was used. This instrument has an excellent intra-observer reliability (ICC between 0,87 – 0,94) in the assessment of the evertors' isokinetic force (Aydog, Aydog, Çakei, & Doral, 2004).

Finally, the data processing and analysis were made using the following software: Matlab R2012a (The MathWorks Inc., Boston, MA, USA) and *Acqknowledge* 3.9 (BIOPAC Systems, Inc. Goleta, USA).

2.3. Procedures

The procedures were divided in two moments: zero moment (M0 – condition without fatigue) and moment one (M1 – condition with fatigue). The M0 and M1 were made on the same day to assure the same location for the gathering of the EMG signal. The M0 always preceded M1.

2.3.1. Zero moment (M0)

Preparation of the participants

The midbelly skin surface of selected muscles and patella of the dominant limb was prepared (shaved and then the dead skin cells and non-conductor elements were removed with alcohol and with an abrasive pad) to reduce the electrical resistance to <5 kΩ. For PL, the electrodes were placed at 25% of the line between the head of the fibula and the lateral malleolus, for the PB the electrodes were placed at 25% of the line between the lateral malleolus and the head of the fibula. These locations were confirmed by palpation, during the voluntary contraction of those muscles. The ground electrode was placed in the patella (Hermens, Freriks, Disselhorst-Klug, & Rau, 2000). The dominant limb was determined asking the participant to kick a ball.

Additionally, three reflector markers with 19 mm of diameter were placed in the posterior face of the leg and on the shoe: (1) 2 cm below the popliteal fold in the medium point between the lateral and medial face, (2) over the Achilles tendon in the alignment of the two malleolus and (3) in the center of the posterior face of the shoe (Beynnon, Renstrom, Alosa, Baumhauer, & Vacek, 2001; Norkin & White, 2009).

The size of the soccer shoe models was selected for each athlete according to the respective foot size ensuring the criteria of a distance of 0,5 cm between the longest toe and the front of the soccer shoe. It’s also important to mention that soccer shoes were new for each participant.

Data collection

Cavanagh's index of each participant was calculated through plant pressure values, obtained during upright standing over 60 seconds. Participants were asked to remain as motionless as possible while looking at a visual reference, located at the eye-line level and at a distance of 3 m (Putti, Arnold, Cochrane, & Abboud, 2008).

After this task, the participant was asked to perform a brief warm-up of the lower limbs for 10 minutes in the cyclo-ergometer with 2% of the body weight, followed by self-directed stretching exercises (Brown, Bowser, & Simpson, 2012). Then, participants were informed that they should perform a three series of five consecutive lateral jumps with dominant foot, at a cadence of 120 beats per minute (controlled by metronome) while wearing one of the three models of cleats provided by ADIDAS (Turf, Hard ground and Firm ground). A 2-minute resting period was set between each series (Caffrey et al., 2009; Docherty et al., 2005). The cadence adopted was based on the maximum cadence executed by healthy individuals in this kind of functional tests (Caffrey et al., 2009; Docherty et al., 2005). All participants were required to reach a minimum horizontal distance of 30 cm in their jumps, with a jump being considered the trajectory both forth and back. A trial was considered valid when the subject reached this distance in each jump with the defined cadence. Participants carried out a series of trials for familiarization with the task, in an attempt to memorize the execution speed and minimizing the effects of the learning process. To diminish the order effect, the sequence of the cleats used to carry out the protocol was previously randomized. The functional test adopted was selected with the intention of serving as a more demanding alternative than the single-footed static positioning tests, widely used in the posture control assessment (Delahunt, 2007a) and was adapted from the Side Hop Test, previously used in the detection of functional deficits amongst individuals with and without ankle instability (Caffrey et al., 2009; Docherty et al., 2005). Figure 2 shows the sketch of the functional test, highlighting the individual's initial position according to the foot used for jumping.

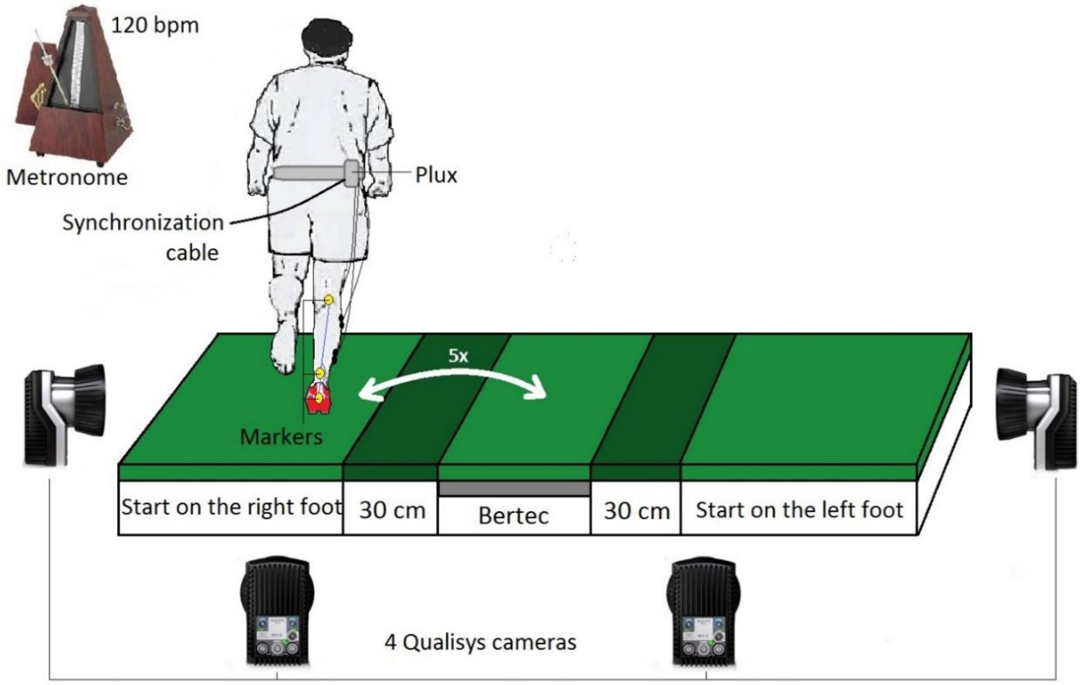

Figure 2: Experimental set up.

2.3.2. Moment one (M1)

Application of the fatigue protocol

After a 5-minute rest interval, all participants were subject to an evertor-oriented concentric/eccentric fatigue protocol in the isokinetic dynamometer, as they are the main ankle dynamic stabilizers in the LAS mechanism (Jackson et al., 2009; South & George, 2007). The eccentric component was included due to a higher production of force and because is more representative of the role of evertors muscles in ankle mediolateral stabilization (Gutierrez, Jackson, Dorr, Margiotta, & Kaminski, 2007; Sandrey & Kent, 2008).

The application of the fatigue protocol was carried out with individuals in a seated position, with their thigh, knee and ankle at 90º, 35º and 80º, respectively. The distal one-third of the thigh and the foot remained supported and stabilized by Velcro straps (Bisson et al., 2011). After 3-5 sub-maximal repetitions (that served as a warm-up and as a means of familiarization with the device), the peak torque was identified through three maximum contractions at 120°/s, in a movement amplitude of 30º (20° of inversion and 10° of eversion). It was determined that the individual reached a state of fatigue when he executed, consecutively, three eccentric contractions below 50% of the peak torque (Gutierrez et al., 2007).

To prevent evertors fatigue recovery, participants performed the jump sequence immediately after the application of the fatigue protocol (40s, in average). Also, between each model, the participant carried out, once more, the fatigue protocol.

2.3.4. Data processing

All variables were analyzed during the three middle foot contact periods and the average values were used for analysis. The signal coming from the force platform was filtered through a low pass fourth-order *Butterworth* filter of 15 Hz and normalized to the body weight. The initial contact with the ground was defined as the moment where the value of the vertical component of the GRF was greater than 10 N (Brown et al., 2012). The loading rate of the vertical (Fz) and medio-lateral (Fx) components of the GRF was obtained by calculating the difference between the maximum and minimum values, divided by the time interval, and it represents the relation between the GRF maximum and the time needed to reach it. The mediolateral (COPx) and anteroposterior (COPy) displacements of the COP were obtained by calculating the difference between the maximum and minimum value of the COP. It was also calculated the mediolateral (V_COPx) and anteroposterior (V_COPy) average speeds for the displacement of the COP, by dividing the displacement by the time interval (Duarte & Freitas, 2010).

A second-order *Butterworth* low-pass filter of 6 Hz was applied to cinematic data. The ankle eversion/inversion range of movement was obtained through the angle between the 'leg' segment and the 'hind foot' segment. In this analysis, the amplitude variation between the maximum eversion and inversion angles during the supporting period was used (Whatman, Hume, & Hing, 2013).

The electromyographic signals were filtered using a zero-lag, second-order Butterworth filter with an effective band pass of 10 to 500 Hz. The root mean square was calculated using a moving average of 20 samples (Schmid, Moffat, & Gutierrez, 2010). The temporal analysis was made in relation to the supporting moment (T0), being defined for each muscle as the time when a value equal to or higher than 5% of maximum obtained in each trial was observed, for at least 30 ms (Hodges & Bui, 1996; Nieuwenhuijzen, Gruneberg, & Duysens, 2002). The start of the muscular activation was searched in a temporal window starting at -250ms in relation to T0 (Shiratori & Latash, 2001). Each of the previously described variables was analyzed before and after the fatigue protocol.

2.4. Statistics

PASW® Statistics 20 (*Predictive Analytics Software*) software was used with a significance level of 0,05. The mean and median were used as measures of the central tendency, and the standard and interquartile deviations as dispersion measures (Marôco, 2010).

ANOVA repeated measures and Friedman tests were used to compare the different models of cleats without and with fatigue (Marôco, 2010). *T-test* for paired samples or the *Wilcoxon* test were used to compare the same cleats between conditions (non-fatigue and fatigue) (Marôco, 2010). Power analysis indicated that for the majority of variables analyzed, 1-β was higher than 60% (Dupont & Plummer Jr, 1990).

3. Results

3.1. Comparison of kinetic, kinematic and neuromuscular variables between cleats, with and without fatigue of the main evertors

No statistically significant differences were found in kinetic, kinematic and neuromuscular factors between the different cleats with and without fatigue of evertors muscle (Table 1).

3.2 Comparison of kinetic, kinematic and neuromuscular aspects obtained with each cleat model between non-fatigue and fatigue conditions

When comparing the obtained parameters in each model of cleats in the two conditions evaluated (with and without fatigue of the peroneal muscles), no statistically significant differences were found in most analyzed variables. The only variable showing statistically significant differences (T = 2,074; P=0,05) was the peroneus brevis activation time (PB_AT) in the Hard ground model. In this model, the activation time was earlier in the condition with fatigue (-0,102 ± 0,093 s), when compared to the condition without fatigue (-0,079 ± 0,095 s). The results are summarized in table 1.

Table 1 - Comparison of cleats and conditions without and with fatigue

		Average ± SD		Comparison of cleats without fatigue		Comparison of cleats with fatigue		Comparison of conditions without and with fatigue	
Variable	Cleats	Without fatigue	With fatigue	Test value	Sample value	Test value	Sample value	Test value	Sample value
AEIROM (degrees)	*TF*	8,90 ± 1,95	9,49 ± 2,27					T = -0,853	0,409
	HG	8,50 ± 1,44	8,99 ± 3,31	*F* = 1,038	0,366	X^2 = 1,714	0,424	Z = -0,220	0,826
	FG	8,16 ± 1,63	8,66 ± 2,62					T = -1,314	0,211
LRVz (N/s)	*TF*	14,10 ± 3,91	13,53 ± 1,67					Z = -1,373	0,170
	HG	14,15 ± 3,17	12,84 ± 1,86	X^2 = 0,348	0,840	*F* = 1,716	0,193	Z = -1,060	0,289
	FG	13,37 ± 2,36	12,73 ± 1,90					Z = 0,675	0,507
LRLx (N/s)	*TF*	2,74 ± 0,78	2,69 ± 0,76					Z = -0,698	0,485
	HG	2,73 ± 0,75	2,43 ± 0,56	*F* = 0,514	0,559	X^2 = 2,000	0,368	T = 1,605	0,123
	FG	2,63 ± 0,81	2,39 ± 0,61					T = 1,273	0,217
COPx (mm)	*TF*	82,65 ± 30,65	75,12 ± 29,52					T = 0,387	0,704
	HG	68,58 ± 28,28	75,18 ± 20,72	X^2 = 1,778	0,411	X^2 = 0,471	0,790	Z = -1,207	0,227
	FG	68,87 ± 21,79	74,65 ± 30,25					Z = -0,213	0,831
COPy (mm)	*TF*	100,86 ± 26,70	103,31 ± 20,43					T = -0,445	0,661
	HG	102,04 ± 26,55	99,05 ± 25,34	*F* = 0,530	0,593	*F* = 1,302	0,283	T = 0,413	0,684
	FG	94,31 ± 14,39	94,93 ± 27,23					T = -0,097	0,924
V_COPx (mm/s)	*TF*	276,50 ± 98,81	258,67 ± 102,86					T = 0,134	0,895
	HG	240,36 ± 97,26	252,61 ± 64,78	X^2 = 0,111	0,946	X^2 = 0,471	0,790	Z = -0,923	0,356
	FG	254,16 ± 106,53	243,24 ± 96,06					Z = -0,065	0,948
V_COPy (mm/s)	*TF*	336,14 ± 76,17	356,44 ± 74,42					T = -1,036	0,312
	HG	349,4 ± 83,33	328,71 ± 75,13	*F* = 0,501	0,609	*F* = 4,228	0,022* *Post hoc* 0,079	T = 0,975	0,341
	FG	332,33 ± 101,17	305,86 ± 87,78					T = 1,076	0,295
PL_AT (s)	*TF*	-0,0551 ± 0,07144	-0,0512 ± 0,06637					T = -0,550	0,588
	HG	-0,0494 ± 0,07106	-0,0361 ± 0,08409	X^2 = 1,000	0,607	*F* = 1,429	0,250	Z = -1,460	0,144
	FG	-0,0496± 0,07229	-0,0550 ± 0,06686					T = 0,158	0,876
PB_AT (s)	*TF*	-0,0991 ± 0,08182	-0,1041 ± 0,05551					T = 0,486	0,632
	HG	**-0,0791 ± 0,09545**	**-0,1024 ± 0,09277**	*F* = 1,172	0,319	*F* = 0,278	0,758	**T = 2,074**	**0,050***
	FG	-0,1067 ± 0,08805	-0,1154 ± 0,08555					T = 0,237	0,815

Legend: (SD – Standard deviation); (TF – Turf); (HG – Hard ground); (FG – Firm ground) (AEIROM – Ankle eversion/inversion range of movement); (LRVz – Loading rate of the vertical force); (LRLx – Loading rate of the lateral force); (COPx – Mediolateral displacement of the COP); (COPy – Anteroposterior displacement of the COP); (V_COPx – Mediolateral displacement speed of the COP); (V_COPy – Anteroposterior displacement speed of the COP); (PL_AT – Peroneus longus activation time); (PB_AT – Peroneus brevis activation time). Bold values represent significant statistical differences.

4. Discussion

Although the main concern of the soccer player is related to performance over safety and comfort (Hennig, 2011; Lake, 2000), it is absolutely relevant to carry out comparative studies between cleats using variables that could be related to injury risk. It should be noted that despite in the present study the selected variables have been related to ankle sprain prediction, evidence supporting this assumption is lacking. Future studies are demanded to support this assumption. The high costs associated with the treatment of lateral ankle sprain (LAS), the risk of subsequent instability (Morrison & Kaminski, 2007) and the reduced volume of bibliography available on the relation between traction imposed by footwear and the LAS (Hennig, 2011) support, thus, this line of investigation focused on health promotion.

4.1. – Comparison of kinetic, kinematic and neuromuscular aspects between cleats, without fatigue of the main evertors

No significant differences were found in any of variables analyzed in a non-fatigue condition. This result contradicts the conclusions of previous studies supporting the relation between higher traction indexes (inherent to higher studs) and a higher risk of injury (Lake, 2000; Queen et al., 2008; Sterzing et al., 2009). The fact that increased mechanical traction does not always lead to high biomechanical forces during direction change movements is a possible justification. Sterzing (2008) assessed the traction indexes of 4 models of cleats through a mechanical instrument (mechanical traction) and had recorded differences between them. However, when comparing different models of cleats in real conditions, those differences disappeared, showing the extreme need of considering the human structure biology during the analysis of traction properties (biomechanical forces) (Sterzing et al., 2008). Another justification may be related to the conclusions of a study that compared 10 models of cleats in four different types of ground (two of which were synthetic turf), through a mechanical instrument that simulated direction change movements, describing a greater influence of the ground in the traction properties rather than of the models of cleats (Villwock et al., 2009).

The biomechanical (ankle inversion/eversion range of movement, loading rate of the GRF, speed and displacement of the COP) and neuromuscular (activation time of the peroneals) variables show very similar values between cleats. These results clearly decrease the relevance of the phenomenon of neuromotor adaptation to the cleats and its properties in healthy subjects. Otherwise the most used model (Firm ground n=15; 62,5%) could have different values in the variables evaluated, because this phenomenon allow players to adjust their movements to the traction properties of the shoe to ground interface conditions (Hennig, 2011).

In healthy individuals, the amplitude of eversion and inversion varies between 5° - 10°, and 25° - 30°, respectively (Dubin et al., 2011). In this study, the average variations remain between 8,16 and 8,90º, which may suggest a good dynamic control regarding this demanding task. Although the foot was stabilized in the shoe, it’s possible that this limited range may be due to the markers' placement on the shoe and therefore less likely to measure a change. In the future, the study of the type of sole support through plantar pressure insoles should be associated to this one, to allow for the description of whether the recorded amplitude occurred with greater or lesser support of the side of the foot - a possible injury risk factor.

In direction change maneuvers, the combination of greater inversion amplitudes and high lateral GRF has been described as a potential injury source (Dayakidis & Boudolos, 2006). In the ground reception after the vertical jump, the increasingly fast growth registry of the vertical forces seems to be a neuromuscular response making the ankle more stable avoiding excessive inversion forces (Dayakidis & Boudolos, 2006). Additionally, the vertical and lateral loading rate is also a comfort indicator inherent to the imposed loads on the articular surfaces, expressing the tissue's ability to accommodate the load (Puddle & Maulder, 2013; Smith et al., 2004). The fact that no significant differences between the cleats were recorded may indicate that the cleats are very similar. At first glance, comparing the rubber sole of the Turf with the plastic one and high studs of the Hard and Firm ground, one could expect that there were differences. Such an hypothesis would be consistent with the results obtained in a previous study that compared a Turf model with a Soft ground one (plastic sole and only 6 high aluminium studs), during a run at two velocities (5,4 and 4,4 m/s), carried out by two male soccer players (Smith et al., 2004). This study showed that the second model imposed higher GRF than those imposed by the first one (Smith et al., 2004). The explanation for the lack of differences in the present study may be related the fact that the grass was in optimal conditions, which allowed for a similar absorbing of the load between models. For optimal conditions, we consider the vertical filaments without the rubber being compacted, allowing for a complete penetration of the higher studs (FIFA, 2009, 2012).

COP displacement-related variable, widely used as postural control indicators (Palmieri et al., 2002) in LAS studies (Morrison & Kaminski, 2007), shows the proximal and distal body adjustments for the task. In most studies, this variable was evaluated in single-footed static positioning (Delahunt, 2007a; Richie, 2001) or during gait (Willems, Witvrouw, Delbaere, De Cock, & De Clercq, 2005). Globally the findings obtained in these studies demonstrate increased COP oscillations in individuals with functional ankle instability compared with subjects without ankle instability. As such, one would expect that, if a cleats model was more unstable (for example, for having excessively high studs, which would not fully penetrate in the synthetic turf), it would end up in significant differences between models, which was not the case. The justification for this phenomenon may be related to the turf conditions. In the present study, the grass was not subject to irrigation and being dry, conferred to the Turf model a more similar traction/stability in relation to the other models. In fact, in more realistic conditions (wet grass) the stability provided by this model (with lowest studs) would possibly be different from the others. In another perspective, if the infill of the synthetic turf was compacted due to an excessive usage, it may not allow the penetration of the Hard and Firm ground models' studs and thus, generate a possible difference between models. However, the penetration of the studs, in this case, does not appear to pose any difficulties. It should also be considered that cleats impose different stability levels and the athlete may have compensated those differences through proximal body strategies. However, future studies are required to confirm our hypothesis. Finally, the divergent characteristics when it comes to the sole and vamp may not have been sufficient to induce different levels of stability during the chosen functional test and also, explain the obtained results.

In the Delahunt (2007) revision, several studies advocate that the muscular strength of the evertors does not seem compromised while comparing individuals with and without functional instability. More important than evertor’s strength, the study of the evertors' muscular reflexes seems to be more important as an injury contributor variable (Delahunt, 2007a; Rosenbaum, Becker, Gerngro, & Claes, 2000). Konradsen (1997) advocates that the mioelectric activity has a delay that can go up to 90 ms due to neural latencies, also associated to an additional 90 ms delay required for the production of half of its maximum force (Konradsen, Voigt, & Højsgaard, 1997). On the other hand, in just 100 ms, the lateral ligament system may be in injury risk, for which it is accepted a muscular pre-activation in dynamic activities, such as jumping (Richie, 2001). In the present study, muscular pre-activation values (peroneus longus and brevis) were recorded with all the cleats, with no statistically significant differences being recorded among them. This fact may be explained considering the results obtained in the variables previously studied, which show an identical degree of instability between the cleats. As such, these will have produced a similar stimulation in the muscular receptors, culminating in an equivalent pre-activation with the different models.

4.2. – Comparison of kinetic, kinematic and neuromuscular aspects between cleats, with fatigue of the main evertors

It is currently accepted that in a fatigue condition the muscle's mechanical properties and proprioceptive system, necessary for postural control, are affected (Bisson et al., 2011; Sandrey & Kent, 2008). When comparing fatigued muscles with non-fatigued ones, the first reveal a decreased production of force and an increase in muscular latency (Hiemstra et al., 2001). Of all the afferent information from the mechanical receptors of the skin, joints and muscles, it seems to be a higher relative contribution of the one coming from the muscle spindles (Konradsen, Ravn, & Sorensen, 1993). That premise is supported by the fact that an anesthesia in the ligaments and joint capsule does not appear to induce alterations in the activation time of the peroneals (Konradsen et al., 1993). As such, one would expect that eventual differences between the cleats in the zero moment were identified/amplified by the induction of fatigue. However, the fatigued condition did not reveal statistically significant changes between the cleats in any of the studied variables. One of the possible explanations is the fact that the isolated fatigue of the peroneals muscles (main dynamic stabilizers that oppose the inversion mechanism) was imposed, with some studies advocating that some muscular groups of proximal action (thigh or knee) appear to have more influence in the posture control than others of a more distal action (ankle) (Bisson et al., 2011). On the other hand, inducing fatigue only in the peroneal muscles may have been insufficient to find differences, as the isolated fatigue of a muscular group of the ankle appears to have a lesser impact than the simultaneous fatiguing of several muscular groups in that articulation (Boyas et al., 2011). Future studies using more global fatigue protocols are required. Furthermore it would be important explore the use of multidirectional jumps – closer to reality game (Caffrey et al., 2009). Finally, because in the present study the *post hoc* analysis indicated that the ideal 1-β values (80%) were not achieved (Dupont & Plummer Jr, 1990), future studies with a higher sample are required to confirm our results.

5. Conclusion

The findings obtained in the present study indicate that in healthy athletes LAS contributors variables are not influenced by different models of soccer shoe. This conclusion is inevitably associated to the particularities of the study, that is, to the fact that the assessment was made through a dynamic functional test adapted from the Side Hop Test, performed by healthy athletes and on a third-generation synthetic turf.

<u>Article III</u> - Portuguese version of the ankle instability instrument

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ABSTRACT

Introduction: Chronic ankle instability is one of the most common clinical conditions in the general population, especially in adult athletes. The cross-cultural adaptation of self-reported questionnaires that identify and classify this condition contribute to criteria standardization in research but also in rehabilitation. Aim: The purpose of this study was to adapt the Ankle Instability Instrument (AII) to the Portuguese population and to investigate its psychometric properties. Materials and methods: Linguistic and semantic equivalence of the original version of AII to the Portuguese population was firstly performed. The Portuguese version of the AII was then applied to 81 higher education adult students, with (n=59) and without history of ankle sprain (n=22). Participants were evaluated two times with an interval of one week to assess the psychometric properties of the Portuguese version of AII. Results: Reliability of the binary responses in test-retest showed that the tetrachoric correlation coefficient ranged from 0,99 to 1,00. Further, the Kuder-Richardson coefficient was 0,79 suggesting a relatively good internal consistency. Conclusion: The Portuguese version of AII presents high reliability.

Key words: Chronic ankle instability, Self-reported questionnaire, Reliability, Cross-cultural adaptation.

1. Introduction

It is generally accepted that self-reported questionnaires are valuable tools not only to identify the subjective impact of different clinical conditions, but also to help establishing the diagnosis in a variety of situations (Simon, Donahue, & Docherty, 2014) Further, their usefulness has been consistently shown, namely in clinical practice and health research because the information provided is highly reliable and inexpensive (Simon et al., 2014).

The Chronic Ankle Instability (CAI) is an example of a clinical condition whose diagnosis is not solely based on objective findings (Hossain & Thomas, 2015), but also in subjective feelings of instability and giving away (Delahunt, 2007a). In fact, in addition to persistent residual pain and edema, this dysfunction is associated to ankle instability symptoms up to 75% of the cases (Hossain & Thomas, 2015).

It has been argued that CAI has a multifactorial aetiology and can involve mechanical and/or functional deficits (Delahunt, 2007a; Hossain & Thomas, 2015). Mechanical instability originates from structural capsule-ligamentous changes and may be defined as a movement of the ankle joint complex beyond its physiological limit (Delahunt, 2007a; Hossain & Thomas, 2015). These mechanical changes lead to altered proprioceptive input and altered motor control programmes (Denegar & Miller, 2002) which, in turn, seem to perpetuate ankle instability. Functional instability results from neuromuscular/proprioceptive deficits and consequent deficit of postural control, which compromise the dynamic stability of the joint complex, being characterized by the ankle giving away sensation (Delahunt, 2007a; Hossain & Thomas, 2015).

The high prevalence of CAI after ankle sprain (Raina & Nuhmani, 2014), one of the most common sport related injury (Fong et al., 2007), highlight the need of developing and validating tools able to identify CAI (Hossain & Thomas, 2015). In fact, ankle sprain has been estimated to occur in 2,15 cases per 1000 individuals per year in the general population (O'Connor, Bleakley, Tully, & McDonough, 2013), and in 4,2 cases in 1000 hours of exposure in athletes (Fong et al., 2007) leading to high health care costs (O'Connor et al., 2013).

Based on the impact of CAI on society and health systems (Boer et al., 2014; Doherty et al., 2014; Kobayashi & Gamada, 2014), the need of developing valid and reliable self-reported tools to assess/classify CAI has been highlighted (Docherty, Gansneder, Arnold, & Hurwitz, 2006; Eechaute, Vaes, & Duquet, 2008; Hale & Hertel, 2005; Hiller, Refshauge, Bundy, Herbert, & Kilbreath, 2006; Ibrahim et al., 2007; Martin, Irrgang, Burdett, Conti, & V, 2005; Roos, Brandsson, & Karlsson, 2001; Ross, Guskiewicz, Gross, & Yu, 2008). This need is amplified by a diversity of criteria used to identify subjects with CAI (Gribble et al., 2014; Pourkazemi et al., 2014). Inconsistent inclusion criteria make difficult to produce scientific evidence that can be extended to the various populations and regions of the world (Gribble et al., 2014). The International Ankle Consortium currently recommends the use of three of self-reposted tools to identify this condition: the Ankle Instability Instrument (AII), the Cumberland Ankle Instability Tool (CAIT) and the Identification of Functional Ankle Instability (IdFAI) (Gribble et al., 2014). When used together, CAIT and AII, have been shown to accurately identify individuals with CAI (Donahue, Simon, & Docherty, 2011). However, only CAIT is adapted to the Portuguese context, culturally and linguistically (de Noronha et al., 2008) highlighting the need to adapt the AII.

The cross-cultural adaptation of the AII to Portuguese would have a significant contribution in the identification of CAI in several countries distributed along the different continents. We believe that this will not only benefit clinicians but will also allow researchers to compare this condition across populations, and most certainly help conducting comprehensive experimental and epidemiological studies.

2. Materials and Methods

2.1. Subjects

The present cross-sectional observational study included 81 higher education students (18 males, 63 females) with (n=59) and without (n=22) history of ankle sprain. Participants were 20,77±2,19 years old, (63,16±9,75 Kg and 1,68±0,07 m). All were physically active: 31 (38,2%) participated in competitive or recreational sports and 50 (61,7%) in jogging or gym activities. Forty-four percent of the participants maintained their physical activity three times a week, usually for a period of 60-90 minutes (55,6%). Participants were excluded if they presented history of bilateral ankle sprain or other type of musculoskeletal ankle injuries, pathologies affecting postural control namely history of lower limb surgery, balance disorders, neuropathies, diabetes, as well as participants taking oral or local anaesthetics. The AII was self-filled with reference to the injury limb in the group with ankle sprain history and to a randomly chosen limb in the uninjured participants (Docherty et al., 2006).

2.2. Instrument

The Ankle Instability Instrument was developed by Docherty et al. (2006) aiming to accurately identify and evaluate individuals with CAI. The AII was initially developed in a physically active young university sample. Further, it is a fast-track instrument since it only has nine closed binary response questions organized in three domains: initial sprain severity, history of instability and instability during daily living activities. It was suggested that any individual with CAI history has a "yes" response to 5 or more questions. It has also been shown that AII is highly reliable (Intraclass Correlation Coefficient, ICC=0,95) in young adults with and without ankle injury history (Docherty et al., 2006).

2.3. Ethical aspects

The study was approved by the Ethics Committee of Escola Superior de Saúde, Politécnico do Porto, with the Certificate nº 1719/2014. All the participants signed a term of consent. The author of the original version of the questionnaire authorized the validation and use of the instrument.

2.4. Conceptual equivalence and linguistic or semantic equivalence

Translation to the Portuguese language of the English AII (Docherty et al., 2006) was done according to the Guidelines for cross-cultural adaptation of self-report measures (Beaton, Bombardier, Guillemin, & Ferraz, 2000). Two professional bilingual translators in Portuguese and English did the forward translation of the English AII into Portuguese. One translator was a physiotherapist and professional translator while the other was a university professor of Social Sciences and professional translator. The translation was done independently of each other (Beaton et al., 2000). A consensus meeting between the two translators was then held in which the independently developed versions were compared. Differences in versions were discussed and a single consensus version was developed (Beaton et al., 2000). Back-translation from Portuguese into English was done by two other professional bilingual translators who were blinded to the original English AII. The back-translation was also done independently. A consensus meeting between the two back-translators was held in which the independently developed versions were compared (Beaton et al., 2000). Finally, an expert committee, consisting of other bilingual physiotherapists and university professors, compared the individually back-translated and final back-translated versions of the Portuguese version of the AII to the English AII with the sole aim to preserve the semantic, idiomatic, experiential and conceptual equivalence. Differences in versions were discussed and a single consensus version was developed and named “Instrumento de Avaliação da Instabilidade do Tornozelo”. This version was later used in a pilot test or "Comprehension Test". Thus, a document titled "Comprehension Test" was distributed to 4 subjects of the target population but who presented exclusion criteria. The purpose of this assessment was to verify the clarity and comprehensiveness of all items of the Portuguese version (Beaton et al., 2000).

2.5. Test-retest reliability and internal consistency

Internal consistency and test-retest reliability were used to assess the “Instrumento de Avaliação da Instabilidade do Tornozelo” reliability. Internal consistency measures the extent to which items, comprising a scale, measure the same construct (Frost, Reeve, Liepa, Stauffer, & Hays, 2007). To assess the internal consistency of the questionnaire items, Kuder Richardson (KR-20) version of Cronbach´s alfa was used because items are on a binary scale.

Although there is no universal cut-point on how sizeable KR-20 should be, there is some agreement on a possible range of values between 0,70 and 0,95 (Frost et al., 2007). Test-retest reliability is the capacity of an instrument to produce equivalent results on repeated administrations when, no real change in health status has occurred within this period (Frost et al., 2007). To evaluate the test-retest reliability participants were asked to complete the Portuguese version of AII in two moments with a 1-week interval. Since all test items have a binary response, the tetrachoric correlation (rho) was used to assess reliability between test and retest (Bonett & Price, 2005; Muthén & Hofacker, 1988).

All statistical procedures were performed using STATA 15 (Data Analysis and Statistical Software) with a 5% significance level.

3. Results

Of all the participants (n=81), 35 were classified with CAI through the AII, while the remaining 46 were considered without CAI (Table1).

Table 1 – Participants classified with CAI using the AII

	Male (n=18)	Female (n=63)	Total (n = 81)
With CAI	6	29	35
Without CAI	12	34	46

3.1. Validation

At the meeting with the 1st panel of judges, a consensus was reached on its translation. After the application of the "comprehension test" no difficulties in understanding were mentioned. Finally, at the meeting with the 2nd panel of judges, it was concluded that the translated instrument had no underlying or ambiguous concepts. Therefore, no changes were made to the "comprehension test" or pre-final version. The content validity of the AII was therefore checked. The definitive version of the instrument, after translation and review by the two panels of judges, is set out in Appendix IV.

An exploratory factor analysis of the original version (n=101) showed that AII had three factors (Severity of initial ankle sprain; History of ankle sprain and Instability during activities of daily life) and reduced the instrument from 21 to 12 questions (Docherty et al., 2006). However, in the present study no Factor Analysis was done for the following reasons: (i) our sample size is very small comparative to the number of items; (ii) since nine items have binary responses, and there is also a possibility for three ordinal responses, a polychoric correlation matrix is need which is not available in SPSS, for example. Even if we had this matrix, and use specialized software as EQS or LISREL, for example, we would not be able to have a satisfactory solution because of convergence problems – small sample size, too few cases per response category, or no cases at all, and missing responses (Byrne, 2006).

3.2. Test-retest reliability and internal consistency

Reliability of the binary responses in test and retest showed that rho varied from 0,99 to 1,00. Further, the KR-20 was 0,79 which suggests a relatively good internal consistency (for further details see Table 2).

Table 2 – Kuder-Richardson coefficient (KR-20) of the AII (Portuguese version)

Item	Obs	Item difficulty	Item variance	Item-rest correlation
1	81	0,7284	0,1978	0,4480
2	81	0,3333	0,2222	0,3666
3	81	0,4444	0,2469	0,2888
4	81	0,6173	0,2362	0,5889
5	81	0,1852	0,1509	0,4332
6	81	0,6296	0,2332	0,4911
7	81	0,6420	0,2298	0,5736
8	81	0,1605	0,1347	0,4205
9	81	0,3951	0,2390	0,6411
Test		0,4595		0,4724

KR-20 coefficient is 0,7910

4. Discussion

The recognition of the impact of CAI on society and health systems has been described for several authors (Boer et al., 2014; Doherty et al., 2014; Kobayashi & Gamada, 2014). Despite the consensus about the importance of this clinical condition, little consistency have been observed in the inclusion criteria of participants with CAI in several studies regarding this thematic (Gribble et al., 2014; Pourkazemi et al., 2014). Inconsistent inclusion criteria make difficult to produce scientific evidence that can be extended to the various populations and regions of the world. To standardize these criteria, the International Ankle Consortium proposed a list of criteria that should be addressed in the definition of CAI. The use of self-report questionnaires has been stated by the Consortium as an important criterion, highlighting the need of its validation for different populations and languages (Gribble et al., 2014).

The present study aimed to perform the cultural/linguistic adaptation of the AII instrument. This instrument was originally developed to evaluate/classify individuals with CAI (Docherty et al., 2006). In the process of linguistic and semantic adaptation, it was not necessary to make substantial changes, highlighting the Portuguese version of the AII as an instrument of easy understanding and interpretation.

For the analysis of test-retest reliability, a week interval was established to guarantee that the participant's condition remained stable and that the participants didn´t memorized the response given at the first moment (MacDermid et al., 2009). The rho values showed indicators of excellent test-retest reliability for all questions (0,99-1,00) being slightly higher to the values obtained in the original version (Docherty et al., 2006). The results of the present study demonstrate values of rho equal to 1 revealing total coherence in the responses at both times. These results can be explained by the fact that higher education students usually take these types of studies very seriously, responding very carefully to all questions in both moments.

When analysing the internal consistency of all test items of the Portuguese version of AII, a relatively good internal consistency (KR-20 = 0,79) was identified, slightly lower than the original version using Cronbach's α (α = 0,89). Since a greater variability of inter-subject responses is associated with a higher internal consistency values (Marôco, 2014), the value obtained in this study can be explained by a smaller variability of responses, in relation to the concept to be measured (presence of CAI).

The results obtained in our study should be compared with those of the original version with some caution, since the statistical tests used were not the same. The binary scale of the items imposed the use of the tetrachoric correlation coefficient in test-retest reliability (Bonett & Price, 2005; Muthén & Hofacker, 1988) and the use of Kuder-Richardson in the internal consistency (Kuder & Richardson, 1937). The statistical tests used by the original author (Intraclass correlation coefficient and Cronbach's α coefficient) are indicated when the items are continuous variables (Marôco, 2014).

Currently, the scientific community already has access to the cultural and semantic adaptation of the CAIT for the Brazilian-Portuguese language. However, the AII and IdFAI do not yet have their Portuguese version. This study adds the possibility of carrying out more comprehensive experimental and epidemiological studies in many countries and continents, using the Portuguese version of the AII.

In this study, the criterion validation was not performed. The use of a quantitative measurement instrument considered gold standard would be important to consolidate this questionnaire as a valuable tool in the identification/classification of individuals with CAI.

Future studies are expected to focus on building, validating and adaptation of more self-report measurements (Hossain & Thomas, 2015), so evidence-based treatment recommendations can be made in different populations and regions.

5. Conclusion

Through this study it was possible to confirm the content equivalence of the Portuguese version of the AII, revealing an acceptable internal consistency and an excellent test-retest reliability.

<u>Article IV</u> - Different cleat models do not influence Side Hop Test performance of soccer players with and without chronic ankle instability

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Journal: (Submitted)

ABSTRACT

Lateral ankle sprain (LAS) is one of the most common sport injury, representing 10-30% of all musculoskeletal disorders. The LAS is enhanced by sport gestures involving changes of direction and landing manoeuvres and is a risk factor for the occurrence of chronic ankle instability (CAI). Despite the cleat model and performance have been already explored, no study evaluated this relation in athletes with CAI. The purpose of the study was to analyse the influence of different soccer cleat models in Side Hop Test performance of athletes with and without CAI. Thirty-nine athletes were divided in two groups, CAI group (n=20) and healthy group (n=19). Each participant performed the Side Hop Test, executing 10 consecutive jumps on dry artificial grass with 4 cleats models. The Qualisys System and two force platforms were used to analyse the test runtime, the distance travelled and the mean velocity. No statistical significant interaction was observed between the group and the cleat model for all variables evaluated. In addition, no differences were observed either between models or between groups. In this specific test, the performance seems to be not influenced by the different cleat models on dry artificial grass in athletes with and without CAI.

Keywords: Soccer shoes; Velocity; Runtime; Ankle Sprain; Artificial grass.

1. Introduction

Being fast and unpredictable, soccer is the most practiced sport worldwide and is characterized by a variety of movements involving different speeds (Sterzing et al., 2009). The evolution of modern soccer was accompanied by the development of artificial grass fields, especially for non-professional competitions, and by the evolution of different cleat models (FIFA, 2009, 2012). This evolution highlights the study of cleat-surface interaction involving artificial grass fields, not only in healthy athletes but also in athletes with postural control deregulation, like following ankle sprains (Silva et al., 2017a).

Ankle sprain is one of the most common injuries in sports, representing 10-30% of all musculoskeletal disorders and about 76% in soccer (Fong et al., 2007; Kobayashi & Gamada, 2014; Ridder et al., 2015). It has been demonstrated that 85% of the sprains damage the lateral ligaments (Morrison & Kaminski, 2007) and 40-75% develop chronic ankle instability (CAI) after this injury (Gerber et al., 1998). This dysfunction involves recurrent ankle sprains with residual symptoms and reports of giving way and instability (Gribble et al., 2014; Hertel, 2002). It has been argued that patients suffer partial deafferentation following ankle sprain, reducing reflex activity that would be initiated by joint mechanoreceptors (Freeman, 1965). A lack of proprioceptive information from partial deafferentation could chronically suppress gamma activation and desensitize the muscle spindle (Khin-Myo-Hla, Ishii, Sakane, & Hayashi, 1999). This mechanism has been interpreted as the basis of chronic ankle instability (CAI) and supports the high incidence of CAI following ankle sprain (Khin-Myo-Hla et al., 1999; Riemann, 2002; Yeung, Chan, So, & Yuan, 1994).

Seeing the performance as one of the major athletes concern (Hennig, 2011), it becomes relevant the study of the factors that can influence this variable, not only on athletes without a history of ankle injury, but also in athletes presenting CAI. The cleat-surface interaction has been subject of several studies (Muller et al., 2010; Silva et al., 2017b; Sterzing et al., 2009; Sterzing et al., 2010). Among the various features of the cleats, the sole importance has been highlighted. The sole should provide enough traction to prevent slipping and to facilitate braking and changes of direction (Conenello, 2010). The diversity of cleats used currently on artificial grounds (Turf (TF), Artificial Grass (AG), Hard Ground (HG) e Firm Ground (FG)) (Hennig, 2011), emphasizes the need to identify which model provides better performance, since only the first two models are indicated by manufacturers as specific to this ground (Conenello, 2010; Silva et al., 2017a; Sterzing et al., 2009).

Considering the exposed, this study aims to analyse the influence of cleats model on the Side Hop Test performance of soccer players with and without CAI. According to our knowledge no study has evaluated the influence of these cleat models on performance of athletes with CAI (Silva et al., 2017a), however because TF and AG models are recommended by the manufactures for artificial grass fields, it can be hypothesized that these models would be associated with better performance in both healthy and CAI athletes.

2. Methods

Thirty-nine amateur male soccer players, with at least five consecutive years of official competition and aged between 18 and 30 years participated in this study. Participants were divided in two groups, one included participants without history of ankle sprain or other musculoskeletal injuries (healthy group, n=19) and the other included participants with CAI (CAI group, n=20). The inclusion and exclusion criteria were stablished based on the International Ankle Consortium Position Statement (Gribble et al., 2014). To be included in the CAI group, individuals must have answered “yes” to question 1 (“Have you ever sprained an ankle?”), along with “yes” to at least four questions related to perceived ankle instability and giving-way episodes of the Ankle Instability Instrument (AII) (Docherty et al., 2006; Gribble et al., 2014). Individuals presenting mechanical instability expressed through a positive drawer test were also included in CAI group (Docherty et al., 2006; Gribble et al., 2014; van Dijk, 2002; Vries, Kerkhoffs, Blankevoort, & Dijk, 2010). Athletes were excluded from both groups if they present surgery or fracture history in both lower limbs and pathologies affecting balance. Participants were excluded from CAI group if the last ankle sprain occurred in the last 3 months (Caffrey et al., 2009; McKeon et al., 2010). In the healthy group, only athletes without previous history of sprain (both ankles), who responded 4 or less "yes" in the AII and who presented a negative bilaterally drawer test was accepted (Docherty et al., 2006; Gribble et al., 2014; van Dijk, 2002; Vries et al., 2010).

The present study had the approval of the Ethics Committee of Escola Superior de Saúde, Politécnico do Porto, having the athletes signed the Informed Consent.

2.1. Instruments

Anthropometric data were evaluated with balance – Seca® 760 (1 kg accuracy), and a stadiometer - Seca® 222 (1 mm accuracy) (SECA, 2014). Dorsiflexion range of motion were assessed with a fluid-filled inclinometer with 1° increments (MIE Medical Research Ltd, Leeks, UK) (Rabin, Kozol, Spitzer, & Finestone, 2015). The Ankle Instability Instrument was designed to classify patients with CAI and has been shown to be a reliable and valid tool (Docherty et al., 2006). The values of vertical component of ground reaction forces (Fz) were used to identify the contact period of the foot in the artificial grass and were acquired using two force plates at a sampling rate of 1000 Hz (FP4060-08 and FP4060-10 models from Bertec Corporation, USA), connected to a Bertec AM 6300 amplifier and to an analogue board (Qualisys, Inc., Sweden) (Silva et al., 2017b). The *Qualisys motion capture* system (four cameras Oqus 1) with an acquiring frequency of 100 Hz was also used to analyse the distance travelled by a marker placed at the calcaneus. The platforms were covered by a 3rd generation artificial grass carpet consisting of polyethylene/polypropylene filaments of 40-65 mm and filled with silica and rubber (Ekstrand et al., 2011; Sterzing et al., 2010; Zanetti, Bignardi, & Franceschini, 2013). Qualisys Track Manager software, 2.7 version, was used for analysis.

2.2. Procedures

Following the anthropometric assessment, weight bearing dorsiflexion range of motion was collected with an inclinometer positioned 15 cm distal to the tibial tuberosity (Rabin et al., 2015). The dorsiflexion range of motion has been used to distinguish the two groups regarding the risk of LAS, associating the decreased dorsiflexion to a higher risk factor of LAS (Noronha et al., 2006). After this, each participant performed a 10-minute warm up in a cycle-ergometer with 2% of body weight at 60 rpm (Silva et al., 2017b). For the functional assessment, participants were informed that they should perform 10 consecutive unipodal and medio-lateral jumps at maximum speed with the dominant limb (Figure 1). Participants had the opportunity to experience the task to reduce the learning effect. This functional test was adapted from the Side Hop Test, previously used for the detection of functional-performance deficits in participants with ankle joint injuries (Caffrey et al., 2009; Docherty et al., 2005). Each participant performed one trial, with each of the four cleat models: TF, AG, HG and FG (Table 1) (Butler et al., 2014; Sterzing et al., 2010). The order of the cleat model was randomized. A reflective marker was fixed on each model on the posterior surface of the calcaneus. As stated in Figure 1, each mediolateral jump was performed between two force plates. Each test started and ended in the same force plate (Caffrey et al., 2009; Docherty et al., 2005) and was considered valid when a minimum distance of 30 cm in the medial-lateral direction was achieved (Caffrey et al., 2009; Docherty et al., 2005).

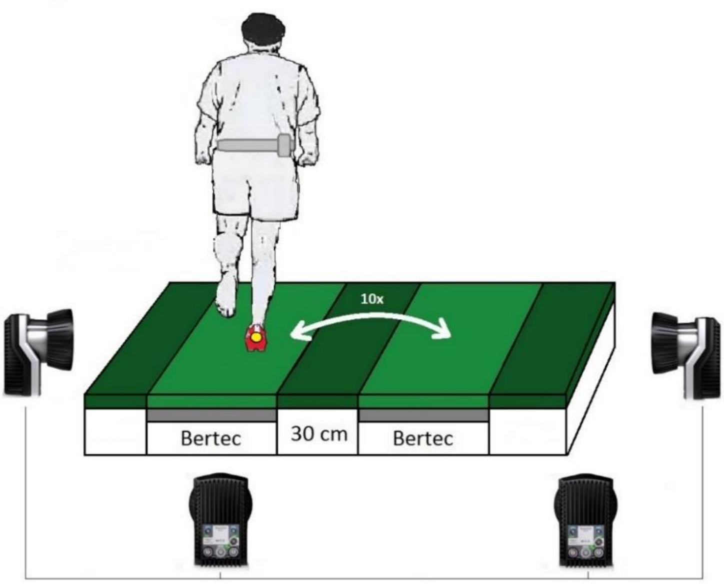

Figure 1: Set up acquisition

Table 1: Cleat's characteristics

	Studs/sole material	Studs		
		Number	Size	Geometry
	Rubber studs and compliant sole	> 55	6-7 mm	Prismatic
		22	8-10 mm	
	Plastic studs and rigid plastic sole	14	10-12 mm	
		11	10-12 mm	

Adapted from (Silva et al., 2017a)

2.3. Data Processing

The signal from the force platforms was filtered through a low-pass fourth-order *Butterworth* filter of 15 Hz and normalized to the body weight (Brown et al., 2012). The test runtime was defined as the time interval between the beginning of the test and the performance of 10 jumps. The beginning of the test was identified as the instant where the value of Fz of the starting force plate was less than 10N. The end of the test was defined as the moment when the Fz value exceeded 10N (Silva et al., 2017b; Smith et al., 2004). A second-order *Butterworth* low-pass filter of 6 Hz was applied to kinematic data (Whatman et al., 2013). The distance travelled was defined as the total distance travelled by the marker placed at the calcaneus during the test runtime. The mean velocity was defined as the ratio of the test runtime and the distance travelled. During the processing and analysis of the data the researchers was blinded considering the group assignment.

2.4. Statistics

Statistical analysis was performed using IBM SPSS Statistics software 21, with a significance level of 0,05. The Shapiro-wilk test indicated that the data was normally distributed. The mean value was used as a measure of central tendency, and the standard deviation as a measure of dispersion. Relative frequencies were also used for descriptive statistics. The repeated measures ANOVA was used for comparing the test runtime, the distance travelled and mean velocity between the four models of cleats. The cleat model was modelled as a within-subject factor, while the group was modelled as a between-subjects factor. The Bonferroni correction was used for *post-hoc* analysis.

3. Results

No differences between groups were observed regarding age ($p=0,586$), height ($p=0,594$) and body mass ($p=0,430$), however decreased dorsiflexion range of motion was observed in CAI group ($p<0,001$). The CAI group reported on average 2,6 sprains and most of the athletes suffered their last sprain more than a year (35%) or two years ago (45%) (Table 2). Regarding the cleats preference (Table 3), no statistically significant differences were observed between groups ($p=0,467$).

Table 2: Sample characterization regarding to age and anthropometric data.

		Healthy group Mean ± SD	**CAI group** Mean ± SD	***p*-value**
Age (years)		21,21 ± 3,28	20,70 ± 2,49	0,586
Body mass (kg)		69,53 ± 7,81	68,38 ± 5,12	0,594
Height (m)		1,76 ± 0,04	1,75 ± 0,06	0,430
Dorsiflexion (degrees)		41,89 ± 4,97	35,48 ± 4,11	<0,001
Number of sprains		-	2,55 ± 1,35	-
How long ago did the last sprain occur relative frequencies (%)	3-6 months	-	10,0	-
	6-12 months	-	10,0	-
	12-24 months	-	35,0	-
	> 24 months	-	45,0	-

Legend: SD - standard deviation

Table 3: Athlete's preference regarding the cleats to use in artificial grass

	Uninjured group (%)	CAI group (%)	*p*-value
TF	0	0	0,467
AG	53	35	
HG	21	40	
FG	26	25	

Legend: TF – Turf; AG – Artificial grass; HG - Hard ground; FG – Firm ground

No significant interaction was observed in test runtime (p=0,559), distance travelled (p=0,961) and velocity (p=0,610) between the group and the cleat model (Table 4). Despite the CAI group have revealed a tendency to higher mean velocity with all models compared to control group, no significant differences where observed between groups (Table 4). Also, no differences between groups were observed in the runtime and distance travelled. When the different models were compared in each group no differences were also observed for the three variables evaluated (test runtime p=0,723; distance travelled p=0,121; mean velocity p=0,476) (Table 4).

Table 4: Performance variables during Side Hop Test in uninjured and CAI groups

Performance variables	Cleat model	Group: Uninjured Mean ± SD	Group: CAI Mean ± SD	Effect size (Confidence interval) 95%	Within-group measures: F	Within-group measures: *p value*	Within-group measures: Observed power	Between-group measures: F	Between-group measures: *p value*	Between-group measures: Observed power
Side Hop Test runtime (s)	TF	7,432±0,613	7,393±0,644	0,062 (-0,37 – 0,45)	0,442	0,723	0,136	0,347	0,559	0,089
	AG	7,561±0,596	7,282±0,485	0,466 (-0,07 – 0,63)						
	HG	7,503±0,693	7,451±0,678	0,076 (-0,39 – 0,50)						
	FG	7,452±0,676	7,384±0,645	0,103 (-0,36 – 0,50)						
Side Hop Test distance travelled (m)	TF	15,845±1,565	15,910±1,279	-0,045 (-0,99 – 0,86)	1,980	0,121	0,498	0,002	0,961	0,050
	AG	16,192±1,594	15,643±1,315	0,376 (-0,40 – 1,50)						
	HG	16,083±1,679	16,345±1,623	-0,159 (-1,33 – 0,81)						
	FG	15,825±1,698	15,956±1,627	-0,079 (-1,21 – 0,95)						
Side Hop Test mean velocity (m/s)	TF	2,137±0,193	2,162±0,194	-0,129 (-0,15 – 0,10)	0,837	0,476	0,227	0,264	0,610	0,079
	AG	2,147±0,207	2,156±0,212	-0,043 (-0,15 – 0,13)						
	HG	2,150±0,200	2,201±0,205	-0,252 (-0,18 – 0,08)						
	FG	2,129±0,198	2,169±0,221	-0,191 (-0,18 – 0,10)						

Legend: SD – Standard deviation; TF – Turf; AG – Artificial grass; HG - Hard ground; FG – Firm ground; CAI – Chronic ankle instability group

4. Discussion

The choice of the footwear has been demonstrated to have impact in variables that can predispose to injury and in variables related to athletes' performance (Conenello, 2010; Silva et al., 2017a). The speed with which athlete moves in the field has become a very important factor in modern soccer. So the ideal cleat should allow the athlete to perform all movements powering traction and stability (Hennig, 2011).

The absence of significant differences in Side Hop Test performance between cleats in both groups, seems to refute the hypothesis that the structural differences of the models are sufficient to influence the athletes' functional performance. Similar results were described when TF, AG and FG models were compared during sprints (De Clercq et al., 2014). Thus, it does not seem necessary to choose a specific cleat model to optimize performance in dry artificial grass fields. However, athletes, coaches and the medical department should be aware of the findings of future studies evaluating the influence of the cleats on the risk of injury specially on CAI players.

It is important to note that the athletes from the present study are not familiarized with the use of TF when playing on artificial grass. This aspect would lead to a worse performance with this model (Hennig, 2011; Muller et al., 2010). However, no differences were observed between this cleat model and the others. The conditions of the artificial grass used in the present study would have contributed to these results, as they differ slightly from the game/practice conditions, and may have influenced the athletes in the performance tasks (Brito et al., 2012; O'Connor & T., 2013). A dry artificial grass may have allowed similar traction between models and this could explain the similar performance values (Sterzing et al., 2009). These results may differ substantially if the study was done with wet grass.

It would be expected that the CAI group present worse performance executing the Side Hop Test (Docherty et al., 2005). In this study, although not verified significant cleat-groups interaction, there was a tendency for better performance in the test by the CAI group. This result could be due to the original test has been described with barefoot participants (Docherty et al., 2005). Its realization with cleats may have provided comfort and ankle stability, reducing possible differences between the groups with and without CAI (Rabello et al., 2014). Finally, the athletes with CAI may have benefited from neuro-motor adjustments arising from injury rehabilitation, providing similar performance values to the healthy group (Caffrey et al., 2009; Clark & Burden, 2005). Although the most common is to evaluate performance during sprint tests, functional tests such as the Side Hop Test can be a very interesting option to assess performance, since they impose an unusual functional task being a major challenge specially for athletes with CAI. Lastly, it should be noted the lower observed power and effect size founded and the need of studies involving a higher sample to confirm our result.

5. Conclusion

Different models of cleats seem to not influence performance expressed by the Side Hop Test runtime, distance travelled and mean velocity in athletes with and without CAI.

Perspective

Performance assessment is a key area in sport, especially in populations with an increased risk of injury. Prior to this study, it has been assumed that the Soft Ground cleat models negatively influence sports performance in artificial grass (Muller et al., 2010; Sterzing et al., 2009; Sterzing et al., 2010). However, their use in artificial grass is strongly discouraged by manufacturers and even prohibit by some Federations such as Portuguese Football Federation. So, there is a need to compare models of cleats that are allowed for this field. Thus, the results of this study suggest that the performance assessed through functional tests does not seem to be influenced by the cleat models in artificial grass. These findings seem to be transversal to athletes with and without CAI. These results highlight the role of performance evaluation using specific and demanding functional tests for certain clinical conditions such as the CAI, warning for the importance of evaluating only cleat models permitted in artificial grass fields. In addition, it will be important to use these results to inform the sports community to choose the cleat model mainly by considering their potential injury risk, rather than their influence on functional performance, as it does not appear to be significant.

<u>Article V</u> - Does the cleat model interfere with ankle sprain risk factors in artificial grass?

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Journal: (Submitted)

ABSTRACT

Background: The cleats-surface interaction has been described as a possible risk factor for lateral ankle sprain. However, their interaction is still completely unknown in individuals with chronic ankle instability (CAI). The purpose of this study was to determine the influence of different soccer cleats on kinematic, kinetic and neuromuscular ankle variables on artificial grass in soccer players with and without CAI. Methods: Eighty-two athletes divided in two groups: 40 with CAI and 42 without CAI. All subjects perform 2 series of 6 consecutive crossover jumps with dominant foot, each one with one of the four models of cleats (Turf, Artificial grass, Hard ground and Firm ground). Kinematic, kinetic and neuromuscular variables were used for the comparison between cleat models and groups. Findings: No statistically significant differences were identified in kinematic, kinetic nor in the electromyographic magnitude of the peroneal muscles between groups or cleats. The CAI group presented later peroneus longus activation timing with Turf model when compared to healthy subjects (p=0,010). The CAI group revealed earlier peroneus longus muscle activation time with the Artificial grass model compared to Turf model (p=0,028). Interpretation**:** In healthy soccer players, the contributing variables for ankle sprain were not influenced by the kind of cleat used in a functional jump test on artificial grass. Players with CAI seem to benefit from the use of the Artificial grass model over the Turf model, due to the early peroneus longus activation time provide by this model.

Keywords: kinematic; kinetic; electromyography; synthetic ground; chronic ankle instability.

Key points:

- Players with CAI should be more careful when choosing cleats for use on artificial grass fields.

- The Artificial grass cleat model appears to promote protective muscular activation against the mechanism of lateral ankle sprain in players with CAI.

- The Turf cleat model appears to promote inadequate muscular activation against the mechanism of lateral ankle sprain in players with CAI.

1. Introduction

With more than 265 million practitioners worldwide (Kunz, 2007), modern soccer become faster, unpredictable and extremely competitive (Sterzing et al., 2009). The development of the ultimate third generation artificial grass fields held the possibility for more hours of practice (FIFA, 2009, 2012) and the several modifications done in the cleats, such as the distribution and the geometry of the studs (Figure 1) (Lees & Nolan, 1998), have contributed to the fulfillment of the player's needs (Conenello, 2010; Sterzing, 2016). Currently there are four types of cleats used in artificial grass fields: Turf (TF), Artificial grass (AG), Hard Ground (HG) and Firm Ground (FG). The TF and AG models are suitable for artificial fields, the HG model for hard natural or dirt soccer fields and the FG model is indicated for natural grass in good conditions (Conenello, 2010; Queen et al., 2008). Despite the recommendations stated for each model, most players select the cleat model based on its stability (Hennig, 2011) grounded on the assumption that it may help to reduce the risk of injuries such as ankle sprains (Silva et al., 2017b).

	Studs/sole material	Número	Studs Size	Geometry
TF	Rubber studs and compliant sole	> 55	6-7 mm	Prismatic
AG	Plastic studs and rigid plastic sole	22	8-10 mm	
HG		14	10-12 mm	
FG		11	10-12 mm	

Figure 1 - Cleat's characteristics - Adapted from (Silva et al., 2017a)

Ankle sprain represents 10-30% of all musculoskeletal disorders (Fong et al., 2007) and about 76% in soccer (Garrick & Requa, 1988). A sudden and unexpected inversion/supination motion (Richie, 2001), with or without plantar flexion (Mok et al., 2011) is the most common injury mechanism (85% of cases) (Morrison & Kaminski, 2007). It has been estimated that from all athletes that suffered an ankle sprain, 40-75% may develop chronic ankle instability (CAI) (Gerber et al., 1998), characterized by persistent residual pain, edema and reports of giving way and instability (Gribble et al., 2014; Hertel, 2002).

Despite the lack of consensus, several intrinsic risk factors for lateral ankle sprain (LAS) have been described: female gender (Doherty et al., 2014); taller and heavier athletes; ankle ligament instability; dominant limb (Beynnon et al., 2002); decreased dorsiflexion (Noronha et al., 2006); ankle alignment deformities (calcaneal varus); type of foot (cavus) (Morrison & Kaminski, 2007); increased center of pressure (COP) displacement (McKeon & Hertel, 2008b; Munn et al., 2010); functional strength asymmetries of the ankle flexors (Fousekis, Tsepis, & Vagenas, 2012); decreased evertor strength (Arnold et al., 2009), increased peroneal muscular activation time (Beynnon et al., 2002) and previous sprain history (Pourkazemi et al., 2014). However, only previous ankle sprain history is considered as a predictor for LAS (Pourkazemi et al., 2014). This fact, corroborates the need of studying athletes with and without CAI (Silva et al., 2017b) due to their close relation to previous history of ankle sprain (Pourkazemi et al., 2014). On other hand, extrinsic factors such as cleat-surface interaction have been studied (Silva et al., 2017a), highlighting the need of identifying an easily modifiable risk factor that help players to reduce different injuries risk. A systematic review demonstrated that different cleat models have been evaluated in terms of risk of injury in cases of calcaneal apophysitis, repeated impact injuries, like metatarsalgia, and knee and ankle injuries related to increased joint loading (Silva et al., 2017a). However, only recently it has been demonstrated that in healthy athletes different cleat models aren´t related to differences in ankle sprain risk factors (Silva et al., 2017b). Moreover, according to our knowledge, and despite deserving the attention of all sports and health professionals (Boer et al., 2014; Kemler et al., 2016), no study has evaluated the influence of different cleat models in ankle sprain risk factors in athletes with postural control deregulation such as CAI.

Therefore, the aim of the study is to evaluate the influence of different cleat models on variables related to the risk of lateral ankle sprain in athletes with and without CAI. Specifically, postural alignment related variables, loading rate of vertical and lateral components of the ground reaction forces; center of pressure (COP) displacement-related variables and neuromuscular variables (onset timing and magnitude of the peroneal muscle) were selected for analysis. Despite the lack of evidence, the results of the present study will be interpreted based on the assumption that increased ankle mediolateral mobility, loading rate of ground reaction forces, center of pressure displacement and muscle onset timing and decreased peroneal muscle magnitude, could be associated to higher ankle instability and a consequent increased risk of ankle sprain.

2. Methods

An experimental intra-subject study design was developed in a sample of federated amateur soccer players, with and without CAI.

2.1 Participants

Eighty-two male athletes, aged between 18 and 30 years, from 32 of a total of 96 clubs of Federação de Futebol do Porto participated in the present study. The sample was divided in two groups based on the presence of CAI: 40 athletes were included in the group with CAI, and 42 in the without CAI group.

To participate in the present study athletes must had federated soccer practice in the last 5 seasons and must be registered at Federação de Futebol do Porto in the current season as well a foot size of 41. Participants assigned to the CAI group met the criteria set by the International Ankle Consortium (Gribble et al., 2014). To be included in the CAI group, athletes should have history of ankle sprains in the dominant limb for less than one year and respond “yes” in 5 or more questions regarding their dominant limb in the Ankle Instability Instrument (AII) (Docherty et al., 2006; Gribble et al., 2014) and presented a positive drawer test (Docherty et al., 2006; Gribble et al., 2014; van Dijk, 2002; Vries et al., 2010). Athletes were excluded if they presented one or more of the following criteria: history of surgery in both lower limbs, pathologies that directly affect the balance, conditions that alter peripheral sensory afferents, any type of neuromusculoskeletal injury beyond ankle sprain in both lower limbs in the last year, and occurrence of ankle sprain in the last 3 months, due to the possibility of still being in an acute or subacute stage (Caffrey et al., 2009; McKeon et al., 2010).

Healthy control participants were selected according to the same exclusion criteria applied to the CAI group and were also excluded if they had history of ankle sprain.

The characteristics of the participants are presented on Table 1. It should be noted that most participants have between 11 and 15 years of official soccer practice (48,8%) and a training period of 7 to 8 hours per week in the current season (36%).

The study was conducted according to the ethical norms of the Institutions involved and conformed to the Declaration of Helsinki, with informed consent from all participants.

2.2 Instruments

Anthropometric data were evaluated with a scale – Seca® 760 (1 kg accuracy), and a stadiometer - Seca® 222 (1 mm accuracy) (SECA, 2014). Dorsiflexion range of motion was assessed with a fluid-filled inclinometer with 1° increments (MIE Medical Research Ltd, Leeks, UK) (Rabin et al., 2015). To control the jump speed, an on-line digital metronome was used (www.metronomeonline.com).

The Ankle Instability Instrument was used to identify athletes with CAI. This instrument presents high values of test-retest reliability (ICC=0,95). Internal consistency reliability estimates (alpha coefficients) for each factor and the total measure ranged from 0,74 to 0,83 (Docherty et al., 2006).

To gather and analyze the ankle eversion/inversion range of motion (AEIROM), the *Qualisys motion capture*® system was used, with 4 cameras (*Oqus* 1) with an acquiring frequency of 100 Hz (*Qualisys AB*, Packhusgatan 6 S-411 13 *Gothenburg* Sweden) and 19mm reflector markers. The range of motion was analyzed only in the frontal plane. This instrument present an excellent intra-observer reliability (ICC = 0,90) for this plane of motion (Sinclair et al., 2012).

The ground reaction forces (GRF) signal was collected with two *Bertec*® FP4060-10/8 force platforms connected to a AM 6300 amplifier (*Bertec Corporation*, 6171 Huntley Road Suite J Columbus, OH 43229 U.S.A.) and to the *Qualisys motion capture*® system. The instrument shows an excellent intra-observer reliability in jump assessments (ICC 0,92 – 0,98) (Hori et al., 2009). The platforms were covered with a 3rd generation artificial grass carpet (6 m^2), composed of polyethylene fibers (60-65 mm) and filled with purified silica and rubber. After the grass carpet installation by specialized technicians, the platforms were calibrated.

The electromyographic signal (EMG) of the peroneal muscles was monitored using a bioPLUX research wireless signal acquisition system (Plux Ltd., Portugal). The signals were collected at a sampling frequency of 1000 Hz and were pre-amplified in each electrode and then fed into a differential amplifier with an adjustable gain setting (25 - 500 Hz; common-mode rejection ratio: 110 dB at 50 Hz, input impedance of 100 MΩ and gain of 1000). Self-adhesive silver chloride EMG electrodes were used in a bipolar configuration and with 20mm between detection surface centers (Dahlhausen®, Köln, Germany). The skin impedance was measured with an Electrode Impedance Checkerd (Noraxon USA, Inc.). While determining the peroneus longus (PL) and peroneus brevis (PB) muscles' activation time, the EMG signal shows an excellent intra-observer reliability (ICC between 0,82 – 0,91) (Hopper et al., 1998).

Finally, the data processing and analysis were made using the following software: Matlab R2012a (The MathWorks Inc., Boston, MA, USA) and *Acqknowledge* 3.9 (BIOPAC Systems, Inc. Goleta, USA).

2.3 Procedures

2.3.1 Preparation of the participants

The muscle belly skin surface of selected muscles and patella of the dominant limb was prepared to reduce the electrical resistance to <5 kΩ. For PL muscle the electrodes were placed at 25% of the line between the head of the fibula and the lateral malleolus, and for the PB muscle the electrodes were placed at 25% of the line between the lateral malleolus and the head of the fibula. These locations were confirmed by palpation, during the voluntary contraction of those muscles. The ground electrode was placed in the patella (Hermens et al., 2000). The dominant limb was determined asking the participant to kick a ball and assuming the dominance as the side which kicked the ball.

Additionally, 3 reflector markers with 19 mm of diameter were placed in the posterior face of the leg and on the shoe: (1) 2cm below the popliteal fold in the medium point between the lateral and medial face, (2) over the Achilles tendon in the alignment of the two malleolus and (3) in the center of the posterior face of the shoe (Beynnon et al., 2001; Norkin & White, 2009; Silva et al., 2017b).

All participants were wearing size 41. Each participant confirmed a distance of 0,5cm between the longest toe and the front of the cleat. It's also important to mention that cleats were new for each participant.

2.3.2 Data collection

All the participants were submitted to a functional test adapted from the 6-meter Crossover Test in a single moment of data collection. Before performing the test, the participants were asked to perform a 10 minutes warm-up in the cyclo-ergometer with 2% of the body weight, followed by self-directed stretching exercises (Brown et al., 2012; Silva et al., 2017b). Then, participants were informed that they should perform 2 series of 6 consecutive crossover jumps with dominant foot, at a cadence of 142 beats per minute (controlled by metronome) while wearing one of the four models of cleats provided by ADIDAS (Turf, Artificial grass, Hard ground and Firm ground). A 2-minute resting period was set between each series (Caffrey et al., 2009; Docherty et al., 2005). The cadence adopted was based on the maximum cadence executed by active individuals in this kind of functional tests (Caffrey et al., 2009; Docherty et al., 2005). Participants carried out a series of trials for familiarization with the task, to memorize the execution speed and minimizing the effects of the learning process. To diminish the order effect, the sequence of the cleats was randomized. The functional test adopted was selected with the intention of serving as a more demanding alternative than the single-footed static positioning tests (Delahunt, 2007a) or the uniplanar Side Hop Test (Silva et al., 2017b) used in the detection of functional deficits amongst individuals with and without CAI. All participants had to respect the distances indicated in figure 2 in their jumps. A trial was considered valid when the subject reached this distance in each jump with the defined cadence and land inside the force plate landmarks (Caffrey et al., 2009; Docherty et al., 2005). Figure 2 shows the sketch of the functional test, highlighting the individual's initial position according to the foot used for jumping.

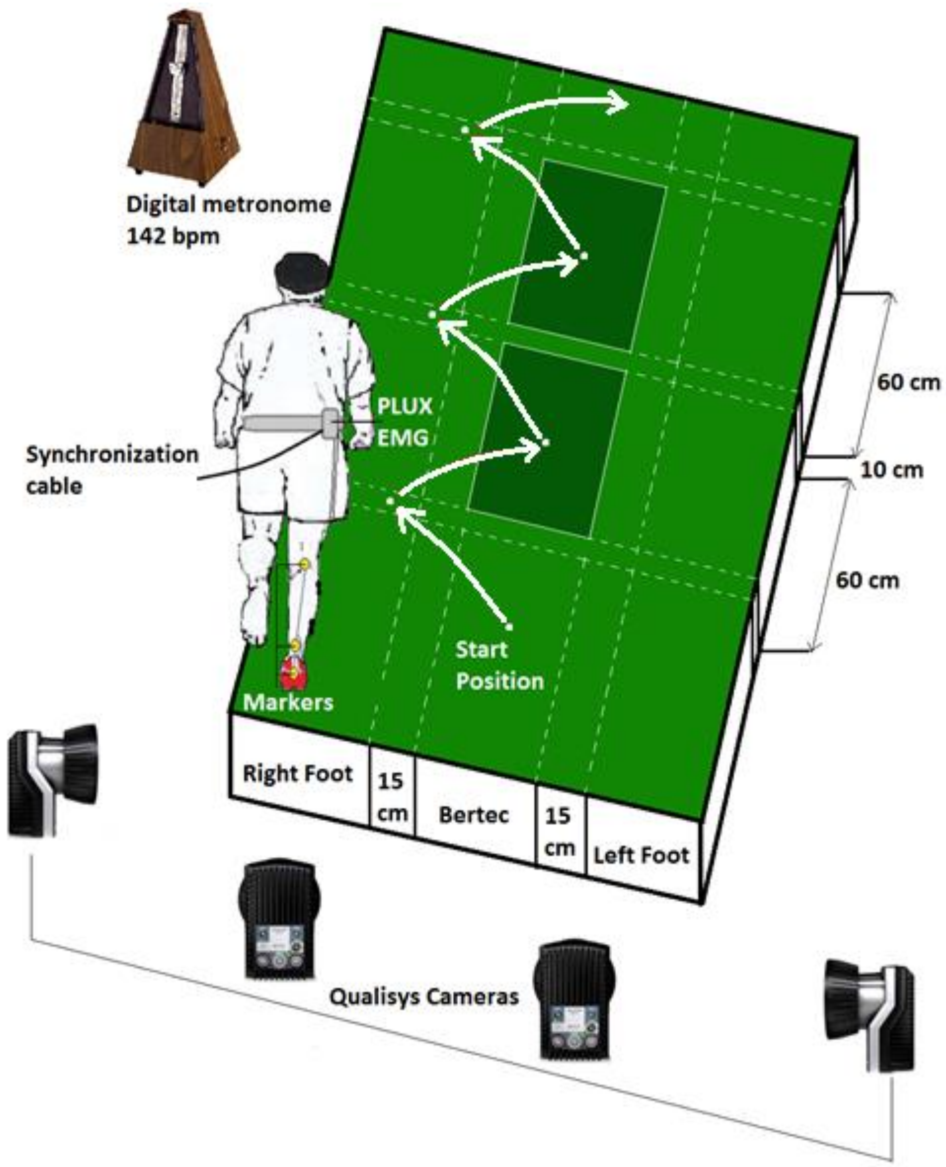

Figure 2 – Data acquisition set up

2.3.3 Data processing

All variables were analyzed during the foot contact periods on force plates and the average values were used for analysis. The signal from the force platform was low pass filtered through a 4th order *Butterworth* filter of 15 Hz and was normalized to the body weight. The initial contact with the ground was defined as the moment where the value of the vertical component of the GRF was greater than 10 N (Brown et al., 2012).The loading rate of the vertical (Fz) and medio-lateral (Fx) components of the GRF was obtained by calculating the difference between the maximum and minimum values, divided by the time interval, and it represents the relationship between the GRF maximum and the time needed to reach it. The mediolateral (COPx) and anteroposterior (COPy) displacements of the COP were calculated for each contact period. It was also calculated the mediolateral (V_COPx) and anteroposterior (V_COPy) average speeds for the COP displacement, by dividing the COP displacement by the time interval (Duarte & Freitas, 2010).

A 2nd order *Butterworth* low-pass filter of 6 Hz was applied to kinematic data. The ankle eversion/inversion range of movement (AEIROM) was obtained through the angle formed between the 'leg' segment and the 'hind foot' segment. In this analysis, the amplitude variation between the maximum eversion and inversion angles during the supporting period was used (Whatman et al., 2013).

The electromyographic signals were filtered using a zero-lag, second-order Butterworth filter with an effective band pass of 10 to 500Hz. The root mean square (RMS) was calculated using a moving average of 20 samples (Schmid et al., 2010). The temporal analysis was made in relation to the instant of foot contact to the ground (T0), being defined for each muscle as the time when a value equal to or higher than 5% of maximum obtained in each trial was observed, for at least 30 ms (Hodges & Bui, 1996; Nieuwenhuijzen et al., 2002). The start of the muscular activation was searched in a temporal window starting at -250ms in relation to T0 (Shiratori & Latash, 2001). The analysis of the magnitude of activation of the peroneal muscles was performed through the mean RMS of the EMG signal during the periods of contact with the platforms. The signal obtained was normalized to the signal obtained during isometric maximal voluntary contractions (MVC) (Akhbari, Ebrahimi, Salavati, Farahini, & Sanjari, 2007). For that, the mean RMS of the interval between the second 2 and second 4 during each MVC were used for analysis. The final values of the analysis (time and magnitude of activation) for each cleat were calculated considering the average of the 4 contacts of the participant on the platforms during the 2 jump repetitions.

2.5 Statistics

PASW® Statistics 20 (*Predictive Analytics Software*) software was used with a significance level of 0,05. The mean and median were used as measures of the central tendency, and the standard and interquartile deviations as dispersion measures (Marôco, 2010).

The chi-square test was used to test an association between a cleat model preference and the groups with and without CAI. The kinematic, kinetic and neuromuscular variables were analyzed by repeated measures ANOVAs. The cleat model was modeled as a within-group factor, while the group was modeled as a between-groups factor. The Bonferroni correction was used for the *post hoc* analysis. T-Student test was used to compared sociodemographic data and the same cleat in different groups (Marôco, 2010).

3. Results

No statistical significant differences were observed between groups as to age, body mass, height and preference of the cleat model (Table 1). Statistical significant differences were observed in weight bearing dorsiflexion range of motion (Table 1). The group with CAI presented decreased values comparing to the group without CAI. In addition, the group with CAI presented 1,9 ± 1,64 ankle sprains in the dominant foot, most of which (39,96%) occurred more than 12 months ago.

Table 1 - Sample characterization

		With CAI	Without CAI	P value
Age (years) - mean±SD		21,4 ± 2,97	21,3 ± 2,63	0,853
Body mass (Kg) - mean±SD		68,8 ± 4,91	69,0 ± 7,19	0,846
Height (m) - mean±SD		1,7 ± 0,05	1,8 ± 0,06	0,734
Dorsiflexion ROM (degrees) - mean±SD		35,8 ± 4,26	41,1 ± 4,04	<0,001*
Cleat model preference for play on artificial grass - relative frequencies (%)	TF model	3,7 %	0,0 %	0,222
	AG model	17,1 %	22,0 %	
	HG model	14,6 %	11,0 %	
	FG model	13,4 %	18,3 %	
Number of sprains in the dominant foot - mean±SD		1,9 ± 1,64	-	-
How long ago did the last sprain occur - relative frequencies (%)	3-6 months	7,58 %	-	-
	6-12 months	20,08 %	-	-
	12-24 months	32,58 %	-	-
	>24 months	39,96 %	-	-

3.1 Comparison of kinematic variables between cleats in both groups: with CAI and without CAI

No statistical significant differences were observed in kinematic variables between cleat models in both groups (Table 2). However, through the analysis of Table 2 a tendency to increased values of AEIROM as well as COP related variables was observed in the group with CAI compared to the group without CAI for majority of the cleat models.

Table 2 – Comparison of kinematic variables between subjects and within-subjects.

Variables / Cleat models		Groups: With CAI mean±SD	Groups: Without CAI mean±SD	Between subjects comparison: With vs Without CAI p Value (1- β)	Within subjects comparison: With CAI p Value (1- β)	Within subjects comparison: Without CAI p Value (1- β)
AEIROM (degrees)	TF	7,4±4,90	5,9±3,24	0,255 (0,205)	0,362 (0,234)	0,144 (0,467)
	AG	6,7±3,30	5,2±2,96			
	HG	6,5±3,36	6,7±4,61			
	FG	6,2±4,60	5,7±3,43			
COPx (mm)	TF	212,2±150,57	174,3±133,30	0,542 (0,093)	0,328 (0,306)	0,240 (0,369)
	AG	195,8±123,33	197,8±148,03			
	HG	199,9±132,91	175,8±126,86			
	FG	186,5±109,82	181,0±125,00			
COPy (mm)	TF	143,6±48,39	158,9±76,67	0,451 (0,116)	0,880 (0,091)	0,153 (0,456)
	AG	147,0±43,89	155,0±58,23			
	HG	141,6±38,42	149,8±59,70			
	FG	144,8±41,40	145,7±57,78			
V_COPx (mm/s)	TF	773,8±531,61	657,6±503,22	0,714 (0,065)	0,496 (0,218)	0,368 (0,282)
	AG	717,5±467,24	742,7±558,14			
	HG	730,1±464,15	686,8±492,53			
	FG	698,8±416,86	687,3±463,95			
V_COPy (mm/s)	TF	519,1±164,21	593,4±263,14	0,242 (0,214)	0,716 (0,139)	0,130 (0,485)
	AG	548,9±163,46	591,4±243,16			
	HG	525,52±140,41	580,9±249,33			
	FG	527,40±181,46	547,0±212,92			

3.2 Comparison of kinetic variables between cleats in both groups: with CAI and without CAI

No statistical significant differences were observed in the slope of Fz e Fx between cleat models in both groups (Table 3). However, it should be note that for both groups the cleat model associated to lower Fz slope values was the AG model (Table 3). Through the analysis of Table 3, it can be also observed a tendency for decreased values for the slope of Fz and Fx in the group with CAI compared to the group without CAI. However, no statistical significant differences were observed between groups for all cleat models (Table 3).

Table 3 – Comparison of kinetic variables between subjects and within-subjects

Variables / Cleat models		Groups		Between subjects comparison	Within subjects comparison	
		With CAI mean±SD	Without CAI mean±SD	With vs Without CAI p Value (1-β)	With CAI p Value (1-β)	Without CAI p Value (1-β)
LRVz (N/s)	TF	23,2±4,62	25,2±7,70	0,241 (0,215)	0,700 (0,067)	0,646 (0,074)
	AG	22,7±4,08	22,8±4,62			
	HG	23,9±6,44	25,1±7,11			
	FG	23,0±3,23	23,8±3,65			
LRVx (N/s)	TF	4,2±1,01	4,5±0,91	0,230 (0,223)	0,747 (0,129)	0,373 (0,279)
	AG	4,3±1,01	4,5±1,31			
	HG	4,2±0,98	4,4±0,75			
	FG	4,2±1,09	4,3±0,89			

3.3 Comparison of neuromuscular variables between cleats in both groups: with CAI and without CAI

No differences were observed in the EMG magnitudes as well as in the PB activation time between cleat models in both groups and between groups for all cleat models (Table 4). On the other hand, it can be observed a statistical significant later PL activation time for TF model in the group with CAI compared to the group without CAI (P=0,010). Furthermore, it can be also observed a statistical significant earlier PL activation time with AG model in the CAI group (p=0,028).

Table 4 – Comparison of neuromuscular variables between subjects and within-subjects

Variables / Cleat models		Groups: With CAI mean±SD	Groups: Without CAI mean±SD	Between subjects comparison: With vs Without CAI p Value (1- β)	Within subjects comparison: With CAI p Value (1- β)	Within subjects comparison: Without CAI p Value (1- β)
EMG_PL (%)	TF	95,6±41,89	104,9±50,86	0,674 (0,070)	0,262 (0,199)	0,642 (0,163)
	AG	103,0±48,14	95,4±32,71			
	HG	102,6±54,24	94,5±33,86			
	FG	94,1±40,81	99,7±45,95			
EMG_PB (%)	TF	93,2±39,77	95,3±31,33	0,472 (0,110)	0,278 (0,339)	0,166 (0,281)
	AG	90.4±31,67	93,8±29,07			
	HG	89,7±30,41	93,0±27,69			
	FG	86,8±29,11	91,9±27,18			
PL_AT (ms)	TF	**-5.3±74.48**	**-64,3±118,76**	0,031* (0,582) TF With>Without **p=0,010***	0,014* (0,791) TF>AG **p=0,028***	0,903 (0,084)
	AG	**-45,7±74.08**	-55,8±84,89			
	HG	-28.9±85.16	-66,1±85,03			
	FG	-38,6±79.56	-41,4±121,53			
PB_AT (ms)	TF	-68,3±81,38	-71,6±109,90	0,757 (0,061)	0,315 (0,313)	0,912 (0,082)
	AG	-84,5±86,56	-67,0±88,14			
	HG	-64,9±81,88	-76,8±81,26			
	FG	-69,1±95,14	-70,7±88,48			

4. Discussion

The results of the present study demonstrate later PL activation time with the TF cleats model in the group with CAI compared to the group without CAI. Also, an earlier PL activation time was observed with AG compared to the TF model in the CAI group. No statistically differences were observed for the other kinematic, kinetic and neuromuscular variables between cleats and groups. The results of the present study should be discussed under the following assumptions: 1) the low degree of unpredictability of the functional test adopted on the present study decreased the test difficulty and the consequent demand over postural control system (Borotikar, Newcomer, Koppes, & McLean, 2008); and 2) all athletes that participated in the present study underwent physical therapy after injury and were competing for at least 3 months without restriction. The effectiveness of proprioceptive training programs in reducing the rate of ankle sprains and improving motor control is well stablish (Schiftan et al., 2015) and may have been a key factor for the few differences between groups.

4.1 Comparison of kinematic variables between cleats and groups: with CAI and without CAI

Although a tendency to increased values of AEIROM as well as COP related variables was observed in the group with CAI compared to the group without CAI for the majority of the cleat models, no statistical significant differences were observed. It could be expected increased values in these variables in the CAI group since these players usually have persistent residual pain, edema and reports of giving way and instability that could impaired their ankle mobility and overall stability (Koshino et al., 2014; Terada et al., 2014). The absence of significant differences could be explained by the fact that our test was performed with cleats, although the original crossover test was described barefoot (Caffrey et al., 2009; Docherty et al., 2005). The use of cleats may have provided greater comfort and ankle stability minimizing the functional deficits expected for this group (Rabello et al., 2014).

When the cleat models were compared in each group, no statistical significant differences were revealed in kinematic variables. In healthy subjects, the eversion/inversion ROM is about 30 to 40 degrees (Dubin et al., 2011). In our study, the players achieved in average around 13% to 25% of the total ROM, which may suggest an appropriate dynamic control for the task. However, it should be noted that in the present study the degree of ankle inversion/eversion was calculated as the total difference, being not possible to identify if the movement occurred in the last degrees of inversion and thus be considered as more dangerous (Morrison & Kaminski, 2007).

Based on the evidence that cleats with studs do not fully penetrate the artificial grass lead to increased instability (Clarke & Carré, 2010), increased values of COP related variables were expected in the present study in cleats with this feature. However, none of the groups presented differences between cleats in these variables, revealing that athletes with and without CAI are able to deal with the postural challenges that different cleats can impose (Buchanan, Docherty, & Schrader, 2008; Caffrey et al., 2009; Docherty et al., 2005). While similar results have been obtained by a recent study which used a similar sample of players without CAI (Silva et al., 2017b), the results in CAI are more surprising. The absence of differences between cleats in the CAI group, could be due to the dry condition and the perfect state of the artificial grass. These particularities could have uniformized the cleat models' behaviour, allowing full penetration to the cleat with higher studs (HG and FG) and sufficient traction to the models with lower studs (TF and AG) (Silva et al., 2017b). Future studies are required to confirm this hypothesis. Considering the evidence demonstrating postural control deficits in joints proximal to ankles with CAI (Bullock-Saxton, 1994; Caulfield & Garrett, 2002; Hertel & Olmsted-Kramer, 2007), future studies dedicated to the kinematic analysis of whole body are required to analyse if the absence of differences in COP related variables are related to hip or trunk compensatory strategies.

4.2 Comparison of kinetic variables between cleats and groups: with CAI and without CAI

The CAI group revealed a tendency to decreased values for the slope of Fz and Fx compared to the group without CAI. It would be expected that the group with motor control deficits would show increased values in ground reaction force variables (Caulfield & Garrett, 2004). Thus, if this trend were more expressive it could indicate that the group with CAI could have adopted motor strategies that facilitated the load accommodation, both vertically and mediolaterally. Also, despite the participants were asked to perform the test with a controlled velocity, the height and length of each jump wasn´t quantified. A possible difference in these variables can be in the origin of the non-existence of significant differences between groups regarding kinetic variables, which agrees with the idea that athletes with CAI not always are adversely affected in their functional performance (Demeritt, Shultz, Docherty, Gansneder, & Perrin, 2002).

A tendency to decreased values for the slope of Fz with the AG model was observed in both groups. If this trend were more expressive could highlight this model as being less harmful (Lake, 2000; Queen et al., 2008; Sterzing et al., 2009) and thus, its use be advised for players with and without CAI. Although some authors believe that increased vertical impact loads compared to mediolateral direction may allow the ankle joint to remain more stable avoiding excessive inversion forces (Dayakidis & Boudolos, 2006), no statistical significant differences were observed, which agrees with the results obtained in the evaluation of healthy soccer players, that used the Side Hop Test alternatively to the 6-meter Crossover Test in a very similar methodology (Silva et al., 2017b). In fact, it is possible that structurally different cleat models imposed different mechanical traction when assessed with mechanical instruments, but similar biomechanical traction when assessed in real conditions with soccer players (Sterzing et al., 2008). Another point of view, argues that changing different playing fields seem to be more important than to use different cleat models to identify differences between models' mechanical properties (Villwock et al., 2009). Thus, the fact that we only used one type of artificial field may help to explain the absence of differences between models in kinetic variables. These results contrast with studies associating higher studs with higher traction indices and consequently an increased risk of injury (Lake, 2000; Queen et al., 2008; Sterzing et al., 2009).

4.3 Comparison of neuromuscular variables between cleats and groups: with CAI and without CAI

To allow comparison of activity between different muscles and individuals, the EMG signal should be normalized in relation to a reference value obtained during standardized and reproducible conditions (Sousa & Tavares, 2012). Usually, the most used method is isometric maximal voluntary contraction (MVC). However, posture and motivation are key factors that can influence this method of normalization. Therefore, the EMG from an isometric MVC may not represent the maximum activation capacity of the muscle at lengths other than those at which the MVC was performed, or under non-isometric conditions (Mirka, 1991). This may be the reason why the mean percentage of magnitude was superior to 100% in some cleats models on both groups.

In the present study, no differences were observed between groups in eversor’s EMG magnitude. Despite the divergence of results regarding eversors' strength deficits in individuals with CAI (Hartsell & Spaulding, 1999; Mattacola & Dwyer, 2002; McKnight & Armstrong, 1997; Pontaga, 2004; Wilkerson, Pinerola, & Caturano, 1997), the results of the present study indicate that athletes with CAI present no impairments in the magnitude of postural adjustments during foot contact with the ground. However, because foot contact period is related mainly to compensatory and accompanied postural adjustments, future studies evaluating the anticipatory postural adjustments are required. The importance of studying this motor control variables is highlighted by the results obtained in the present study regarding muscle onset timings.

Despite both groups presented peroneal onset timings related to feedforward mechanisms, delayed activation of PL was observed in the TF model in CAI group (almost 60 ms of delay). Interestingly, this difference is only noticed with the cleat model that practically no athlete is accustomed to play with. This finding, together with the non-existence of significant differences between model in the group without CAI, highlight the importance of the neuromotor adaptation to the cleat in the neuromuscular performance of the CAI group (Hennig, 2011). Coaches and health professionals should alert CAI athletes to the risk of using this model, especially if they are not accustomed to it. The differences between models were observed in the CAI group indicate that the specificities of this clinical condition potentiate the cleats structural differences expressed through different PL activation timing. In fact, it has been argued that patients suffer partial deafferentation following ankle sprain, reducing reflexive activity that would be initiated by joint mechanoreceptors (Freeman, 1965). A lack of proprioceptive information from partial deafferentation could chronically suppress gamma activation and desensitize the muscle spindle (Khin-Myo-Hla et al., 1999). The delayed PL activation observed in the TF model compared to all the other models and significantly to AG model in the CAI group corroborate this assumption. The preference for the AG over the TF model can help to explain this result, since safety perception associated to a familiar model can positively influence the motor planning (Muller et al., 2010). However, it should be also considered that the reduced stud size of the TF model could have led to an insufficient penetration in the artificial grass field decreasing the traction index (Sterzing et al., 2010; Villwock et al., 2009) with a consequent smaller stimulus to the muscle receptors. Consequently, the AG model with intermediate size studs may have empowered an optimum traction index due to the full stud penetration that promote an increased contact area between the cleat and the surface (Clarke & Carré, 2010; Lake, 2000; Queen et al., 2008; Sterzing et al., 2009). In closed kinetic chain, the PL stabilizes the first ray and everts the foot to transfer body weight from the lateral to the medial side of the foot (Andrews, Harrelson, & Wilk, 2012). It should be noted that despite differences between groups and cleats in PL onset timing wasn´t accompanied by differences between groups and cleats in kinematic and kinetic variables for the functional test performed, probably in more demanding tasks the differences observed in muscle activation timings could interfere with kinematic and kinetic variables increasing the risk of injury. Future studies involving more demanding postural tasks are demanded to confirm this hypothesis. It should be also considered the low observed power obtained in the present study for the kinematic and kinetic variables future studies with higher sample are required to confirm our results.

Also, considering the limitations previously stated, future studies should analyse the influence of cleats on wet artificial grass fields, possibly with a few years of use, using full body kinematics, and evaluating dynamic tasks with some degree of unpredictability.

5. Conclusion

The findings obtained in the present study indicate that in healthy soccer players, the contributor variables for ankle sprain were not influenced by the kind of soccer cleat in a functional test on a third-generation artificial grass. However, players with CAI seem to benefit from the use of the Artificial grass model over the Turf model, especially if they are not accustomed to playing with it, due to the early PL muscular activation timing provide by this model.

6. GENERAL DISCUSSION

The findings obtained in the studies presented in the previous chapters have contributed to the achievement of the purposes stated for this thesis. Specifically, the findings obtained have contributed to the understanding of: (i) the cleats' influence on variables related to lateral ankle sprain injury risk of soccer players without CAI in artificial grass, with and without fatigue, (ii) the cleats' influence on performance of soccer players with and without CAI in artificial grass and (iii) the cleats' influence on variables related to lateral ankle sprain injury risk in soccer players with and without CAI in artificial grass.

Through our systematic review, we aimed to assess what is already known about the cleats influence on the performance but also on the risk of injury. For this purpose, we have considered all articles that compared different models of soccer cleats, regardless the sample characteristics, the competitive level, the field of play and the type of variables under study. Although this work does not respond directly to the objectives of the thesis, it gave a significant contribution for the designing of our experimental studies and also for the compilation of necessary knowledge to fill the methodological flaws or limitations presented in previous studies. These limitations were related to the sample, the biomechanical variables selected and the functional task. For this, it was very important to define a priori which clinical condition to evaluate (ankle sprain). This choice facilitated several methodological options as mention on methodological considerations (chapter 4). Thus, it was possible to: i) improve the inclusion/exclusion criteria of both healthy and CAI group, ii) compare only approved cleat models for artificial grass fields, iii) analyse variables related to specific ankle sprain risk factors, iv) improve the accuracy of the performance evaluation, v) study a demanding dynamic task related to the injury mechanism and vi) study the influence of the cleats under the condition of fatigue. The results of this review sustained the hypothesis that different cleat models are related to different performance and injury risk levels (Hennig, 2011; Kulessa et al., 2017; McPoil, 2000; Silva et al., 2017a; Sterzing, 2016). This evidence has supported our hypothesis regarding cleats-surface interaction and its impact in variables related to performance and risk of injury. However, despite the TF model seems to present promising results regarding the risk of repetitive impact related injuries, this can´t be transferrable for injuries related to different mechanisms like ankle sprain. These findings emphasise the need of evaluating the influence of the cleat model on both performance and the variables related to the risk of the most frequent soccer injury in artificial grass fields – ankle sprain. Despite it was not stated as objective of this thesis, the results obtained in this review have contributed to our decision about the kind of field that should be explored. Our primary decision was based on the fact that this field is the most used by the most expressive subgroup of soccer players (non-professionals). The results of this review by demonstrating an increased risk of injury in this field compared to natural grass, even with the most protective models, have sustained our decision. Additionally, the importance of the inclusion of artificial grass is also supported by the notion that the conclusions obtained in previous studies included cleat models that nowadays are not recommended by some soccer federations for this kind of field, compromising the ecological validity of the conclusions obtained (FPF, 2017). To overcome this limitation those models (SG models) were not included in our experimental studies, so that the conclusions can be transferred to a real context.

Surprisingly accordingly to our knowledge only our first experimental study assessed the influence of different cleat models on the ankle sprain injury risk (article II). Article II responded directly to the first objective of this thesis. When TF, HG and FG models were compared during a functional task involving consecutive mediolateral jumps, there appears to be no differences in the variables related to the LAS risk of injury even after a specific evertors fatigue protocol (Silva et al., 2017b). However, these results should be interpreted with caution as this fatigue condition does not exactly mimic the typical fatigue of a game or a training session. Despite this, evertors isokinetic fatigue protocol has the advantage of being selective for the most important active stabilizers during inversion mechanism (Jackson et al., 2009; South & George, 2007) and may also privilege the eccentric contraction that is more related to the mechanism of injury (Gutierrez et al., 2007; Sandrey & Kent, 2008). In addition, it proved to be an incomparably faster method to induce fatigue than a soccer match simulated effort on a treadmill, for example (Greig & Siegler, 2009). The time spent in data collection is always a key factor for the sample's adherence to the study, and this was another reason why we chose this methodology. On the other hand, the longer the fatigue protocol, the more likely it will induce perspiration, which could compromise electrode adherence to the skin as well as signal fidelity (Abdoli-Eramaki, Damecour, Christenson, & Stevenson, 2012; Türker & Sözen, 2013). Despite this, the fatigue condition was something innovative and should be precursor for further studies in this area of knowledge. Although it may present some limitations/difficulties, future studies should explore methodologies that impose fatigue similar to a soccer match, using, for example, an intermittent treadmill protocol replicating the activity profile of a soccer match (Greig & Siegler, 2009). The difficulty in this type of protocol will be to ensure that each athlete achieves the same level of fatigue, since the most well-conditioned may eventually not reach the same level of fatigue as a less conditioned athlete. One possible solution would be to objectively and/or subjectively quantify fatigue and to adapt these treadmill protocols until all athletes reach the same degree of fatigue.

The findings obtained in article II led us to verify if these results are maintained in soccer players with postural control deregulation related to ankle sprain as CAI. For that, and because the identification of CAI is based also in subjective criteria we have adapted the AII for the Portuguese population as a form of identifying athletes with CAI (article III). Although the International Ankle Consortium advised the use of the AII or the CAIT (Gribble et al., 2014), we chose not to use this last questionnaire because the Portuguese version is presented as an adaptation to Brazilian-Portuguese language (de Noronha et al., 2008). Through the title, the author of this cultural adaptation seems to intend to restrict the use of this questionnaire only to the Brazilian population, perhaps because it has linguistic expressions that are not adapted to the population used in the present study. For example, in question 6 we can read " My ankle feels unstable when ... I hop from side to side ... I hop on the spot ... When I jump". In the Brazilian-Portuguese version we can read “Sinto instabilidade no tornozelo quando … pulo de um lado para o outro numa só perna… quando pulo no mesmo lugar numa só perna…

quando pulo com as duas pernas”. This version chooses to use the verb “pular”, while the population in Portugal is more familiar with the verb “saltar”. Parallel to the use of subjective scales or questionnaires to identify individuals with CAI, the use of functional tests batteries that objectively identify these individuals have been encouraged (Caffrey et al., 2009; Docherty et al., 2005). In fact, the Side Hop Test and the 6-meter Crossover Test, have already been shown to be able to distinguish individuals with CAI from individuals without CAI (Caffrey et al., 2009; Docherty et al., 2005). For the present thesis we chose to follow the consortium's recommendation using the AII as an inclusion criterion, and to use these two functional tests as tasks for comparing the different cleat models. Besides contributing indirectly for this thesis, we hope that this article would contribute to the creation of a pool of tools (suggested by the International Ankle Consortium) able to identify in a clearer way the individuals with CAI in the Portuguese population.

The fifth study aimed to identify the best cleat model to prevent the lateral ankle sprain injury risk in healthy and CAI soccer players. Our results revealed a lack of significant differences between cleat models regarding kinematic, kinetic and neuromuscular variables related to LAS injury risk in healthy athletes. These results agree with those described in our first experimental study (Silva et al., 2017b), which seems to minimize the concern about cleat model choice in healthy athletes that aim to reduce the risk of LAS. This seems to be true even when the task presents an increasing degree of difficulty, since compared to the Side Hop Test, the 6-meter Crossover Test has been executed at a higher speed and presents displacements in more than one plane of movement. However, we do not know what the results would be if the field was wet, or if the task had more unpredictability, so it may be abusive to think that athletes without previous ankle sprain history can indiscriminately use the cleat models they want. One reasonable option seems to be to advise healthy athletes to use, in artificial grass fields, the cleat models that are associated with a lower risk of LAS in the group with CAI. The results obtained in the comparisons between cleat models in the CAI group proved to be extremely relevant for health promotion in sport. In our study, the AG model revealed a significantly earlier PL activation time when compared to the Turf model. In addition, the comparisons between groups revealed that the Turf model in the CAI group presents the greatest delay in PL activation time, which seems to associate this model to an increased risk of LAS. Interestingly, despite both groups were not accustomed to use this model in artificial grass fields, only the CAI group was negatively affected using this model. Thus, the development of programs related to LAS prevention policies must consider that AG model should be highlighted as protective, especially for athletes with CAI and the Turf model as potentially harmful in this same group of athletes, especially if they are not accustomed to use this latest model. The players' technical gesture intrinsic variability may have masked possible differences between cleat models regarding the risk of LAS assessed through kinematic and kinetic variables. However, the neuromuscular variables, namely the activation time, seem to have a prominent role, being the only one able to distinguish the models from each other. The most reported neuromuscular deficits related to CAI are based on the peroneal activation in response to experimentally induced inversion perturbations (Delahunt, 2007b; Gutierrez, Kaminski, & Douex, 2009; Gutierrez et al., 2012; Konradsen & Ravn, 1991; Lofvenberg, Karrholm, Sundelin, & Ahlgren, 1995; Lynch, Eklund, Gottlieb, Renstrom, & Beynnon, 1996), and the researchers typically measure the activation time after a disturbance via a trap door (Konradsen & Ravn, 1991; Lofvenberg et al., 1995; Lynch et al., 1996). These types of studies have made an important contribution to CAI knowledge, however, the study of muscle activation in functional activities such as walking, running or jumping can be equally important (Feger et al., 2015). Since, dynamic stabilization of the ankle is attributed to preparatory and responsive muscle activity of the extrinsic muscles, the role of preparatory muscle activation is related to an increasing muscle stiffness to control rapid joint rotation that occur after ground contact (Santello, 2005). Thus, preparatory muscle activity must be seen as a protective mechanism that occur in a predictable pattern during learned tasks being proportionally related with the expected stimulus on ground contact (Santello, 2005). Consequently, post contact muscle activity and dynamic joint stability likely are extensions of preparatory muscle activity combined with reflexive responses (Santello, 2005). In this regard, we should see the electromyography has a valuable tool in the study of motor control and the importance revealed by neuromuscular variables in our study may, in the future, guide new research methodologies, more efficient preventive programs aiming to improve motor performance related to muscle activation times and even new preventive methods.

Globally, from a risk of injury prevention perspective, the findings obtained in articles II and V demonstrate that while in healthy athlete the choice of the cleat models (TF, AG, HG and FG) seem to not have a determinant influence, in athletes with CAI the AG seem to have an increased protective effect by promoting an earlier activation of a relevant stabilizer muscle. These conclusions need to be validated in a perspective of performance.

The results of this thesis regarding performance are mainly concentrated in article IV. This study aimed to identify if the cleat models influence performance in healthy and CAI soccer players. This experimental study, revealed that the cleat models seem not to influence performance, at least in functional tasks involving multiple mediolateral jumps (Side Hop Test). Despite the most common performance tests in soccer are straight-line sprints or with direction shifts (Muller et al., 2010; Sterzing et al., 2009; Sterzing et al., 2010), we believe that we could highlight the differences between models using the Side Hop Test procedures because they impose for both healthy and CAI athletes a challenging task, for which the athletes are not so accustomed (Caffrey et al., 2009; Docherty et al., 2005). In contrast to the studies that only evaluate the runtime (Sterzing et al., 2009), our study also evaluated the distance travelled by the foot, to realize if similar values in runtime (between models or groups) could be associated to an improved performance, if the distance travelled for the same runtime was greater. This variable seems to be a valuable tool in the interpretation of the data and should be incorporated in the studies that evaluate sports performance. Although some studies have identified differences in sport performance between cleat models in natural and artificial grass (Muller et al., 2010; Sterzing et al., 2009; Sterzing et al., 2010), others show no differences on dry artificial grass (De Clercq et al., 2014). It is important to mention that those studies that identified differences between cleat models often associated the SG model to decreased performance in artificial grass (Muller et al., 2010; Sterzing et al., 2009; Sterzing et al., 2010) despite this model is not allowed in this kind of field (FPF, 2017). The inclusion of this model seem to have a determinant effect on the presence of significant differences between cleat models, because when this model wasn´t included no differences were observed (De Clercq et al., 2014) as occurred in our fourth article. Although the structural differences in the sole of the different models may induce distinct levels of mechanical traction (Sterzing et al., 2008), the specific conditions of this study (dry artificial grass) made the differences apparently not to have induce any functional adaptation, providing the same performance between cleat models in both groups. On one hand, the absence of differences of performance between cleats in the healthy athletes can be expected because in dry conditions even the models with lower studs seem to allow a proper traction for the task. On the other hand, although some authors stated that CAI does not affect lower extremity functional performance (Demeritt et al., 2002), it would be expected that at least the CAI group would be more influenced by the different cleat models, since this group presents objective and subjective functional deficits that could compromise the functional tasks (Martin et al., 2013). A key factor for the absence of differences in performance in the comparison between soccer cleats in the CAI group and between groups may lie in the same reason – functional rehabilitation after injury. It should be considered that most of the participants of the CAI group (80%) had suffered the last sprain for more than a year and all benefited from rehabilitation after injury which may have diminished the expected functional deficits in this group (Martin et al., 2013). From the sport physiotherapist point of view, the results presented in article IV is of extreme importance since it devalues the importance of the soccer cleat models in the performance, leaving the idea that the cleat’s influence on injury risk should play a much more significant role in the players' choices when purchasing their footwear. These findings indicate that the use of AG model in artificial grass has a higher protective effect without compromising performance.

7. MAIN CONTRIBUTIONS ACHIEVED

The elaboration of this thesis contributed to the improvement of the scientific knowledge about the cleat-surface interaction, both in performance and injury risk that can be helpful in different domains.

- A compilation/systematization of scientific articles that study the cleat-surface interaction regarding sports performance and injury risk in a specific sport modality (soccer) that can be useful to provide athletes and all sports community with more knowledge about the benefits and harms of the models available in the market, as well as being a precursor to the development of new models of soccer cleats. The methodologic option of excluding articles related to other modalities such American football and rugby improve the results' interpretation. Although the three modalities use cleats, all present different rules and different sports gestures, and should not be analysed together.
- From an ecological an epidemiological perspective this thesis provides the study of an easily modifiable risk factor (cleats) in the most practiced sport in the world (soccer), regarding its most frequent injury (LAS), in the most representative population of players (amateur male players), in the most used type of field (artificial grass). Since ankle sprain is the most frequent injury and a high percentage of players evolve into the CAI clinical condition, it makes sense to pool efforts in the study of cleats' influence also in this population, regarding performance but specially the LAS injury risk.
- The inclusion of the fatigue effect in the cleat-surface interaction contributed to highlight the importance of this variable as a possible enhancer of the risk of injury. Studies in this area of knowledge may in the future help to redefine preventive programs, eventually incorporating changes in regulatory game time, or in the inclusion of proprioceptive exercises in controlled environment but under fatigue conditions.
- The possibility for health professionals and researchers to use a self-reported questionnaire to identify and select individuals with ankle instability, which is recommended by the International Ankle Consortium. The cultural adaptation

to the Portuguese language will enable the elaboration of experimental studies with more rigorous inclusion criteria in Portuguese speaking populations around the globe.

- To promote clarifications regarding cleats' influence on sports performance in players with and without CAI. This knowledge may once again benefit athletes and all sports community when it comes to choosing the cleat model, but also the manufacturers to create models that satisfy the sports needs of the players, being aware that a significant percentage of them may present substantial functional deficits such as those associated to players with CAI.
- Compile vital knowledge to focus on LAS prevention without compromising performance. From a sports physiotherapist point of view, this work will contribute to the promotion of preventive policies based on the dissemination of knowledge to health professionals, sports agents, parents of athletes and athletes themselves. Encouraging the correct adaptation of cleat models to the playing field may in the future prevent thousands of LASs, reducing the associated costs with the injury, as well as reducing residual symptoms in cases where it was not possible to avoid injury.

8. CONCLUSIONS AND FUTURE WORK PERSPECTIVES

The two domains of this thesis (risk of injury and sports performance) were addressed in our literature review, where the Turf model was highlighted as being associated with lower plantar pressures compared to other models with studs and therefore, can be seen as a protective model, in particular for repeated impact injuries. On the other hand, the Soft Ground model in dry or wet artificial grass fields and the Turf model in wet fields were associated with worse sports performance.

The results of our experimental studies allowed us to respond directly to our three objectives outlined in the thesis. First, in healthy soccer players (without previous history of ankle sprain) the TF, HG and FG cleat models showed no differences in kinetic, kinematic and neuromuscular contributor variables for lateral ankle sprain during the Side Hop Test in artificial grass even under a fatigue condition. When the same cleat models were compared together with the AG model in healthy players during the 6-meter Crossover Test, the absence of differences for the same variables was maintained. Second, during the Side Hop Test in artificial grass, the different cleat models do not influence the performance of healthy players nor with CAI. Third, athletes with CAI benefit from the use of AG model in artificial grass, since it potentiates an earlier Peroneus Longus (PL) activation time compared to the TF model. The CAI group revealed later PL muscle activation time with the TF model when compared to group of healthy athletes. Thus, the AG model seems to best serve the interests of the players when they play on dry third-generation artificial grass fields.

In future studies, it will be important to repeat our experimental methodologies with the same objectives, but on wet field conditions, using less predictable functional tasks and inducing fatigue more similar to that imposed during a soccer match. If possible, the kinematics of the whole body should be analysed, during the landing, but also immediately before. Furthermore, researchers and health professionals should concentrate their efforts on four main lines of research: (i) epidemiological studies to evaluate the effectiveness of intervention based on lectures about the best cleat model to reduce LAS injury risk; (II) development of cleat prototypes that promote the prevention of LAS and study the mid cut cleats (p.e. Adidas predator 18+); (III) improvement of the artificial grass so that they resemble even more natural grass fields and (IV) creation of new preventive methods possible to be used in conjunction with the cleat or even better, that can be used independently of the sport.

The first line of research should use the knowledge gathered about cleat-surface interaction on performance but specially on injury risk and evaluate the effectiveness of preventive policies based on the dissemination of this knowledge. Epidemiological studies should be encouraged in multicenter studies. The creation of good habits regarding the cleats choice and adequacy to the field of play should have as target young players, integrating whenever possible the parents and technical staff of their teams, or soccer schools. Well-informed players will be in the future healthier players. If soccer is seen as a universal phenomenon, it can and should be a vehicle for health promotion globally.

As some authors have investigated/developed cleat prototypes to improve performance in artificial grass, the creation of prototypes that reduce the risk of injury should be strongly encouraged, especially for the most frequent injuries. Researchers, manufacturers and especially players should carefully consider the advantage/disadvantage of having a cleat model that slightly improves performance but increases the risk of injury significantly.

The increased competitiveness of soccer must be accompanied by the development of new materials that make artificial grass closer to natural fields, with regards to shock absorption. The fact that FIFA encourages the use of synthetics especially in countries with adverse climatic conditions makes this line of research benefit many practitioners.

Finally, the creation of new preventive methods that can be used in conjunction with the most protective cleat model, has made us reflect and led to the creation of a new patented socks that aim to prevent the LAS. The creation of this new preventive method was not a primary objective of the thesis and for that reason will be presented in the appendix V.

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APPENDIX I – Ethical approval

ESTSP | POLITÉCNICO DO PORTO

PARECER DA COMISSÃO DE ÉTICA

Número de Registo da Comissão de Ética: ___________0779/2014___________
Data recepção do Documento: ____________05/03/2014___________

Parecer final da Comissão de Ética:
O parecer é favorável, cabendo ao Investigador Responsável o estrito cumprimento dos condicionalismos apontados.

Data: 07/01/2015
Assinatura:

ESCOLA SUPERIOR DE TECNOLOGIA DA SAÚDE DO PORTO
DATA 22 JAN 2015
N.º [illegible]
ENTRADA

SGS ESTSP.011.CE.08.02

Todos os documentos submetidos à C.E. são objecto de total confidencialidade

Número de Registo da Comissão de Ética: ___________1719/2014___________
Data recepção do Documento: ____________28/05/2014___________

Parecer final da Comissão de Ética:
O parecer é favorável, cabendo ao Investigador Responsável o estrito cumprimento dos condicionalismos apontados.

Data: 30/05/2014
Assinaturas:

ESCOLA SUPERIOR DE TECNOLOGIA DA SAÚDE DO PORTO
DATA 11 JUN 2014
N.º [illegible]
ENTRADA

SGS ESTSP.011.CE.08.02

Todos os documentos submetidos à C.E. são objecto de total confidencialidade

Número de Registo da Comissão de Ética: ___________1331/2015___________
Data recepção do Documento: ____________24/04/2015___________

Parecer final da Comissão de Ética:
De acordo com os dados analisados o parecer é favorável, ressaltando o facto de que o investigador deverá cumprir todas as directrizes submetidas a esta Comissão, com prejuízo de a decisão ser suspensa caso haja algum incumprimento grave.

Data: 12/05/2014
Assinaturas:

ESCOLA SUPERIOR DE [illegible]
14 MAI 2015
N.º 001652
ENTRADA

Figure 1 - Ethical approval of the studies developed

APPENDIX II – Informed consent form

ESTSP | POLITÉCNICO DO PORTO

TERMO DE CONSENTIMENTO INFORMADO

Declaração de consentimento informado

Conforme a lei 67/98 de 26 de Outubro e a "Declaração de Helsínquia" da Associação Médica Mundial

(Helsínquia 1964; Tóquio 1975; Veneza 1983; Hong Kong 1989; Somerset West 1996, Edimburgo 2000; Washington 2002, Tóquio 2004, Seul 2008)

Designação do Estudo: ESTUDO DO TIPO DE CHUTEIRAS COMO FACTOR PREDISPONENTE A ENTORSES DA TIBIOTÁRSICA E NA PERFORMANCE EM PISO SINTÉTICO DE TERCEIRA GERAÇÃO

Eu, abaixo-assinado (NOME COMPLETO DO INDIVÍDUO PARTICIPANTE DO ESTUDO):

Fui informado de que o Estudo de Investigação acima mencionado se destina a estudar que modelo de chuteiras é mais indicado para terreno sintético, tendo como objectivo evitar entorses do tornozelo e potenciar a performance.

Sei que neste estudo está prevista a realização de um teste funcional (multi-saltos médio-laterais) com e sem fadiga, sendo registada a performance com os seguintes instrumentos: plataformas de forças, palmilhas de pressões plantares, sistema de vídeo 3D e electromiografia, tendo-me sido explicado em que consistem e quais os seus possíveis efeitos. A fadiga será induzida por exercícios específicos.

Foi-me garantido que todos os dados relativos à identificação dos Participantes neste estudo são confidenciais e que será mantido o anonimato.

Sei que posso recusar-me a participar ou interromper a qualquer momento a participação no estudo, sem nenhum tipo de penalização por este facto ou interromper a qualquer momento a participação no estudo, sem nenhum tipo de penalização por este facto.

Compreendi a informação que me foi dada, tive oportunidade de fazer perguntas e as minhas dúvidas foram esclarecidas.

Aceito participar de livre vontade no estudo acima mencionado.

Também autorizo a divulgação dos resultados obtidos no meio científico, garantindo o anonimato.

Nome do Investigador e Contacto: Diogo César de Freitas Silva Cesar.diogo@gmail.com

Data	Assinatura
___/___/_____	______________________________________

Figure 1 - Informed consent form

APPENDIX III – Sample characterization questionnaire

No âmbito do Doutoramento em fisioterapia, venho solicitar a vossa participação num estudo científico onde se objetiva estudar a influência do tipo de chuteiras na predisposição a entorses do tornozelo. Irão ser estudados algumas variáveis associadas ao mecanismo de lesão durante uma manobra funcional usada frequentemente no desporto (salto médio-lateral). Cada indivíduo será monitorizado durante todo teste através da eletromiografia, análise de vídeo 3D e plataforma de forças. Os testes serão realizados primariamente sem fadiga e repetidos após protocolo de fadiga. O objetivo final do estudo será atuar ao nível da prevenção desta patologia, junto de toda a comunidade desportiva.

Dados pessoais

Iniciais do nome: ______________ Data de Nascimento ____/____/______

Peso: ______ (kg) Altura: ______ (cm) Tamanho de calçado: ________

Clube: __________________ E-mail: (facultativo) ______________________

1- Há quantos anos consecutivos pratica futebol federado? ______________ (anos)
2- Qual a posição que ocupa habitualmente em campo? ______________________
3- Durante a presente época desportiva, em que tipo de terreno executa a maior parte dos treinos? ___________________ (Relvado natural, sintético ou pelado)
4- Quando joga em piso sintético, qual destes modelos de chuteiras usa preferencialmente? Tenha em atenção o tipo de sola e não a marca utilizada (sublinhe a opção correta)


Turf Ground


Artificial Grass


Hard Ground


Firm Ground

5- Incluindo treinos e jogos, quantas horas pratica futebol por semana? ___________ h/semana
6- Alguma vez praticou outra modalidade desportiva? Se sim, qual? ___________
7- Já sofreu alguma entorse no tornozelo? (assinale a opção correta). Se não, passe para a questão 8. Sim ___ Não ___

   7.1- Se sim, há quantos meses aconteceu a última entorse? ________ (meses)

7.2- Quantas dessas entorses afetaram o pé esquerdo? ___________________

7.3- Quantas dessas entorses afetaram o pé direito? ______________________

7.4- Após a/as entorse/s, foi sujeito a reabilitação em fisioterapia?

Sim ___ Não ___

7.5- Desde a última entorse, utiliza habitualmente algum tipo de proteção para o tornozelo durante os treinos ou jogos? Sim___ Não ___ Qual? __________

8- Indique que lesões já contraiu nos membros inferiores, como por exemplo ruturas musculares, fraturas, roturas ligamentares? (Indique o tipo de lesão, em que membro inferior se desenvolveu e há quanto tempo foi):

Tipo de Lesão	Membro Afetado (Esquerdo ou Direito)	Mês/Ano que se lesionou

9- Durante a presente temporada, teve alguma lesão que o impediu de treinar e/ou jogar durante pelo menos um dia? Sim ___ Não ___

9.1- Se sim, que tipo de lesão, local e tempo esteve afastado (semanas)?

Tipo de Lesão	Membro Afetado (Esquerdo ou Direito)	Data da lesão e tempo de paragem

Obrigado pela sua colaboração

APPENDIX IV – Ankle Instability Instrument

Final version of the Ankle Instability Instrument Portuguese version, reviewed by the panel of judges, for left and right ankle.

Instrumento de avaliação da instabilidade do tornozelo ID:_____________

Este formulário será usado para categorizar a instabilidade do seu tornozelo. Por favor, preencha o formulário na totalidade. Se tiver alguma dúvida, por favor, pergunte ao investigador. Obrigado pela sua participação.

1. Alguma vez já torceu o seu tornozelo?

□ Sim □ Não

2. Alguma vez consultou um médico por causa de uma entorse do tornozelo?

□ Sim □ Não

2.1. Se sim, como é que o médico classificou a sua entorse mais grave do tornozelo?

□ Ligeira (grau I) □ Moderada (grau II) □ Severa (grau III)

3. Alguma vez utilizou algum auxiliar de marcha (como muletas) por incapacidade de suportar o peso corporal devido a uma entorse do tornozelo?

□ Sim □ Não

3.1. Se sim, na entorse mais grave do tornozelo, quanto tempo utilizou o auxiliar de marcha (muletas) referido anteriormente?

□ 1 a 3 dias □ 4 a 7 dias □ 1 a 2 semanas □ 2 a 3 semanas □ > 3 semanas

4. Alguma vez teve a sensação de o seu tornozelo ceder/falhar?

□ Sim □ Não

4.1. Se sim, quando foi a última vez que o seu tornozelo cedeu/falhou?

□ < 1 mês atrás □ 1 a 6 meses atrás □ 6 a 12 meses atrás □ 1 a 2 anos atrás □ >2 anos atrás

5. Alguma vez sentiu o seu tornozelo instável durante a marcha em superfície plana?

□ Sim □ Não

6. Alguma vez sentiu o seu tornozelo instável durante a marcha em piso irregular?

□ Sim □ Não

7. Alguma vez sentiu o seu tornozelo instável durante atividades recreativas ou desportivas?

□ Sim □ Não

8. Alguma vez sentiu o seu tornozelo instável ao subir escadas?

□ Sim □ Não

9. Alguma vez sentiu o seu tornozelo instável ao descer escadas?

□ Sim □ Não

Original version - Ankle Instability Instrument ID:_____________

Instructions

This form will be used to categorize your ankle instability. A separate form should be used for the right and left ankles. Please fill out the form completely. If you have any questions, please ask the administrator of the survey. Thank you for your participation.

1. Have you ever sprained an ankle?

□ Yes □ No

2. Have your ever seen a doctor for an ankle sprain?

□ Yes □ No

2.1. If yes, how did the doctor categorize your most serious ankle sprain?

□ Mild (grade I) □ Moderate (grade II) □ Severe (grade III)

3. Did you ever use a device (such as crutches) because you could not bear weight due to an ankle sprain?

□ Yes □ No

3.1. If yes, in the most serious case, how long did you need to use the device?

□ 1 a 3 days □ 4 a 7 days □ 1 a 2 weeks □ 2 a 3 weeks □ > 3 weeks

4. Have you ever experienced a sensation of your ankle ‘‘giving way’’?

□ Yes □ No

4.1. If yes, when was the last time your ankle ‘‘gave way’’?

□ < 1 month □ 1 a 6 months ago □ 6 a 12 months ago □ 1 a 2 years ago □ >2 years

5. Does your ankle ever feel unstable while walking on a flat surface?

□ Yes □ No

6. Does your ankle ever feel unstable while walking on uneven ground?

□ Yes □ No

7. Does your ankle ever feel unstable during recreational or sport activity?

□ Yes □ No

8. Does your ankle ever feel unstable while going up stairs?

□ Yes □ No

9. Does your ankle ever feel unstable while going down stairs?

□ Yes □ No

APPENDIX V – Prevent Sprain Technology socks

The Prevent Sprain Technology (PST) socks (PATENT PROTECTED) were created based on an innovative concept that incorporate, in a single piece of cloth, the theoretical foundations and characteristics of two methods widely used in the prevention of this injury - Functional tapping/bandages and Ankle Supports (Figure 1) (Dizon & Reyes, 2010; Evans & Clough, 2013; Karlsson et al., 2009; Kemler et al., 2016). Thus, these new socks will be compared with the existent methods in the market (functional tapping/bandages, ankle supports and conventional socks).

Figure 1 – a) Functional tapping/bandages;
b) Ankle supports and c) Prevent Sprain
Technology socks

This concept is not intended to replace existing methods, but to be an integrated solution, indicated for athletes without history of ankle sprain or for those who have completed a rehabilitation program and do not require high restrictive methods of restraint for return to the activity. Thus, it is important to clarify that these socks are not indicated for those how are in an acute or subacute phase of the rehabilitation after an ankle sprain. Objectively, these socks should be used as a strategy for ankle sprain prevention, but also in performance enhancement.

A detailed technical description of the socks will not be presented due to patent protection (Figure 2). However, we can say that the orientation of the fibers that constitute the socks respect the orientation of the tension straps in the functional tapping/bandages and ankle supports.

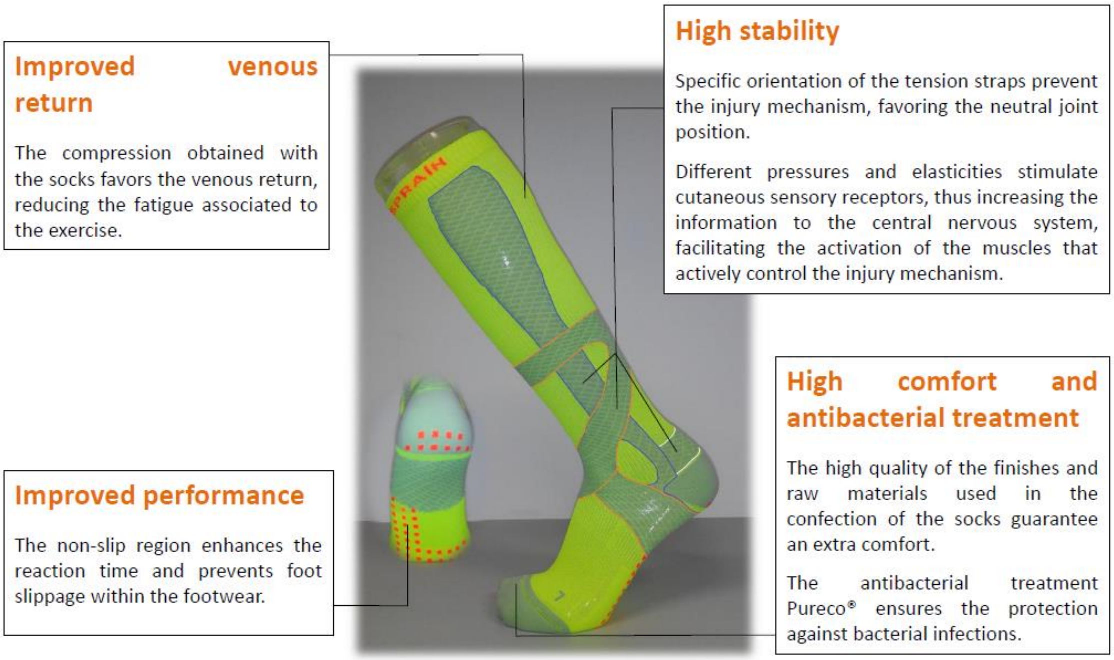

Figure 2 - Technical description: Socks Characteristics

Why do we have created a new preventive method?

Ankle sprain is a health problem that should be managed with prevention as the best possible solution, instead of a problem solve-based approach. Since preventive policies best serve the interests of general society, it is essential to focus on methods of simple application that can be applied in a large population, and that at same time, promote autonomy and an active lifestyle with impact in quality of life. Thus, the easiness of implementation of this preventive method in sports communities and in the general population, regardless of age, physical activity level or gender, makes this prevention method the perfect vehicle to benefit the largest number of people in the world. Furthermore, in sports such as soccer, these socks can be used as an additional method to the best cleat model to further potentiate the prevention of ankle sprain.

This new method has several advantages:

Generic advantages

- The socks are reusable, do not lose the elastic and containment properties throughout the activity and do not require a qualified health professional for their application. For these advantages also contribute other features of the socks that provide comfort and durability during and between uses, namely by avoiding zones of skin friction. These advantages would have a significant impact in the general population because the traditional adhesive functional tapping/bandages do not respond well to users' needs, since they are not reusable, they lose part of their stabilizing capacity during physical activity due to sweat, they need a health professional for their application and cannot be used very often due to the possibility of skin damage by the adhesive material.

- Because the socks are a piece of cloth essential to sports practice it promotes adherence to the preventive program, since the user will hardly forget it. The same does not happen with the other available methods (ankle bandages and ankle supports) which, as an "additional" part of the sportwear is often not added to the sports bag by forgetfulness.

- These new socks will allow the user to maintain the same levels of sensitivity to contact with the ball, a factor of extreme importance in sports such as soccer and futsal. On the other hand, the existing solutions, "ankle bandages + conventional socks" or "Ankle supports + conventional socks", reduce this sensitivity, impairing the performance, namely of the assertiveness of the pass. When the athlete associates a preventive method to decreased performance, often lead to the poor adhesion to that preventive method. With these new socks solution, this problem does not arise.

Advantages for ankle sprain prevention

- Primary prevention – These new socks may prevent/remove an individual's exposure to a risk factor before he or she experiences their first ankle sprain. On the other hand, bandages and ankle supports, due to their discomfort and associated costs, are not usually seen as primary prevention measures.

- Secondary prevention – These new socks will allow the clinical evolution of individuals who have suffered an ankle sprain, with the advantage of favouring an active joint control by the neuromuscular apparatus of the individual, which contrasts with the predominantly passive stabilization of the rigid ankle supports.

- Tertiary prevention – These new socks aim to reduce the social and economic costs of ankle sprain related chronic dysfunctions like chronic ankle instability through an early rehabilitation/reintegration and to enhance the remaining functional capacity of individuals.

Advantages related to sports performance

- Speed – These socks intend to improve the reaction time that would be favoured by the existence of an outer plantar face with non-slip zones that are able to decrease the foot slip inside the footwear and to improve the movement sensation. The existence of non-slip zones only on the outside of the socks, will guarantee the comfort of the individual.

- Fatigue resistance/endurance – The fact that the entire sock is designed with compressive characteristics up to the knee region favours venous return, assisting the calf pump. This would reduce the fatigue associated with the accumulation of metabolites due to exercise. On the other hand, ankle bandages and supports present a too selective compression for the ankle region, not promoting the venous return associated with the calf pump.

Advantages related to Comfort

- These new socks present a higher comfort compared to the solutions already available in the market, since unlike the ankle bandages, the socks do not use adhesive material in contact with the skin and do nott have rigid materials like some ankle supports. Additionally, because occupies a limited space in the footwear contribute to an increased comfort, witch contrasts with the other methods of containment (bandages and supports).

Economic advantages

- Individual – the costs associated with acquiring these new socks will be lower than buying regular sports socks + ankle bandages or ankle support + compression garments/shiners to improve venous return.

- Sports clubs – The acquisition of this new preventive method by the clubs presents an advantage, as it will save the money spent on the acquisition of non-reusable material, like bandages. By encouraging a reduction in the number of injuries and their severity will reduce the cost with athletes out of competition, an impact of extreme importance mainly in professional clubs.

- Health systems – These socks will be an important advance in effectively reducing the number of first sprains and recurrent sprains, as well as reducing the severity of those that cannot be avoided. By preventing the injury from occurring or decreasing its severity, this new sock model may help avoiding invasive surgical interventions (used in 20% of the most serious cases). As a successful preventive method, it will reduce emergency care, as well as expensive and harmful diagnostic methods (x-rays and CT scans).

Social Advantages

- The fact that socks are a piece of cloth usually used, make them go unnoticed when used for clinical reasons in a non-sporting context, fostering the psychological well-being of the user. Contrary to what happens with ankle bandages or supports, which easily identify the individual as having functional limitation, socks do not impose this negative psychological connotation on the user, thus fostering social inclusion.

Ecological advantages

- Aware of the urgent premise of avoiding waste and encouraging reuse, these socks are a more environmentally friendly solution as they are a reusable prevention method. On the other hand, solutions such as functional bandages do not fulfil the purposes of a sustainable environmental solution since they use glues in their straps that are completely disposable, cannot be used by other persons and not allow their reuse even by the same individual.

Generic description of the new solution

Socks were design to promote:

Prevention, through a double stabilization (passive and active). The passive stabilization will be obtained by the specific orientation of the fibers that compose the socks, contrary to the mechanism of injury (inversion and/or supination). On the other hand, the active muscular stabilization will be obtained by the different pressures and elasticities of material that will stimulate specific skin sensory receptors, thus increasing the afferent information to the central nervous system, facilitating the intrinsic muscular activation of the main stabilizing muscles that actively control the injury mechanism.

Performance, through traction zones of non-slip material on the plantar surface of the sock, fundamentally to improve the reaction time and prevent the foot from slipping inside the footwear. On the other hand, having an ascending compression (less compression on the calf and high compression on the ankle) will promote venous return, reducing fatigue, which allow better performance. Since fatigue appears to be a predisposing factor for traumatic ligament injuries such as ankle sprain, the promotion of venous return could also be an indirect way to prevent ankle sprain.

Description of at least one way of the invention

Figure 3 – Socks' description

In its most complete version (up to the knee – figure 3), the socks will have heterogenous compression. The zones of greater compression are identified with the numbers 1; 2a; 2b; 2c and 3. These are anatomic regions with important cutaneous and articular receptors, which benefit from extra compression. The band 1, which accompanies laterally the peroneals alignment, intends to create some resistance to pronosupination movements, so in its medial face the lever arm is smaller, ending in a band of anchorage/fixation 2a. On the other hand, band 3 is intended to minimize adduction/abduction movements. In addition, the bands 2b and 2c together restrict the movement of plantar flexion, as well as eversion/inversion, like ankle supports. The regions with the number 4 are regions of lower compression compared to those described above, being important for example to maintain a correct blood flow to the Achilles tendon, avoiding too much compression on this region. Finally, number 5 represents the zones with non-slip material, key factor for optimization of the performance.

Ongoing research

Several studies are currently being conducted aiming to compare this new preventive method to standard socks and sports compression socks in qualitative and quantitative studies in different sports such as soccer, futsal, basketball, handball and volleyball. While the qualitative studies use a questionnaire specifically created for this purpose, the experimental studies use different instruments, such as the trap door, isokinetic dynamometer, force plates, balance systems, motion capture systems, electromyographic devices etc. These instruments intend to assess variables related to ankle sprain injury risk such as, muscle activation time and magnitude, joint position sense, kinaesthesia, center of pressure distribution and their velocity, time to stabilize, range of motion, etc.

If the results of these studies demonstrate that this new method has the potential to reduce the risk of injury, epidemiological studies should be carried out and the dissemination of this knowledge will be a major step to benefit many sportsmen and women worldwide.